VOLUME XXXIV NUMBER 5 WHOLE NUMBER 294

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

EDITOR, C. A. CHANT ASSISTANT EDITOR, F. S. HOGG
David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS
R. MELDRUM STEWART
Dominion Astronomer
Ottawa

W. E. HARPER
Director of the Dominion Astrophysical Observatory
Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

PUBLISHED MONTHLY
(*Ten numbers per year*)

May-June, 1940

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

VOL. XXXIV, No. 5 MAY-JUNE, 1940 WHOLE No. 294

Articles PAGE

On the Physical Characteristics of the Wolf Rayet Stars and their Relation to Other Objects of Early Type (with Plate VIII and IX) ..... *C. S. Beals* 169

The Work of the Mount Wilson Observatory ..... *W. S. Adams and F. H. Seares* 198

Review of Publications

The Pinpoint Planetarium, by Armand N. Spitz (*C.A.C.*) 206

Notes and Queries

Death of Dr. W. E. Harper—The Mirror for the Radcliffe Telescope (*F.S.H.*) 207

Meetings of the Society

At Victoria — At Vancouver — At Edmonton — At Winnipeg — At Toronto 208

Upon request, made previous to publication of article, contributors will be supplied free with twenty-five copies of the sheets containing the article attached to a printed cover.

If separate reprints are desired the cost will be about as follows:

	4 pp.	8 pp.	12 pp.	16 pp.	20 pp.	24 pp.
50 copies....	$3 50	$5 50	$9 50	$10 00	$13 00	$16 00
100 copies....	4 00	7 00	10 00	11 00	14 00	18 00
200 copies....	4 50	8 00	11 00	12 00	15 50	20 00

Covers, extra, 50 copies, $1.50; 100 copies, $2.00; 200 copies, $2.50.

Business correspondence, remittances, etc., should be addressed to J. H. Horning, Treasurer of the Society, 198 College Street, Toronto.

Communications regarding Library matters should be addressed to the Librarian.

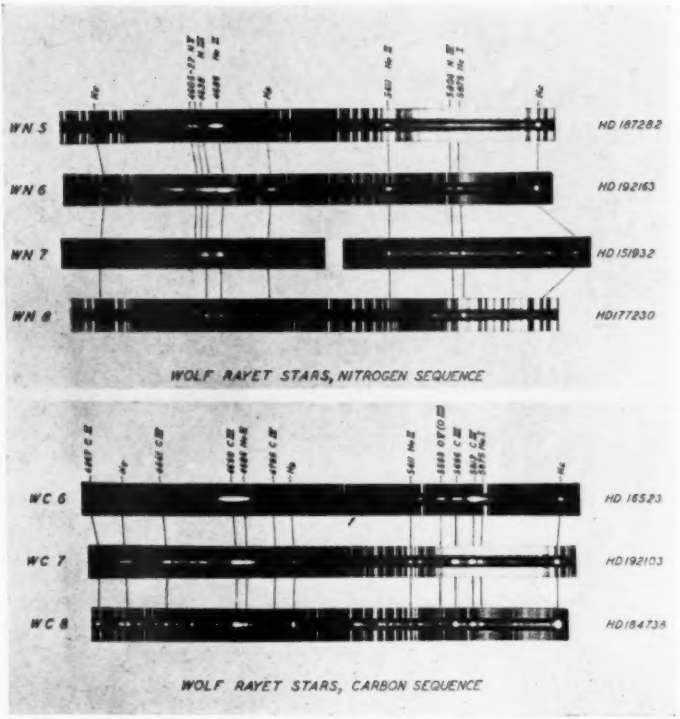
$2.00 per annum. Single numbers, 25 cents.

Subscription to the JOURNAL is included in membership fee.

For Sale—6-inch Newtonian Reflecting Telescope (see illustration in this JOURNAL page 341, October 1939.) This telescope with aluminised mirror, duraluminum tripod and altazimuth mounting, weighs only 35 lbs. Eyepieces with 50x and 100x magnification. A highly accurate, well finished, but very inexpensive telescope. Produced and sold by the Shaw-Hopkins Laboratory, Victoria, B. C.

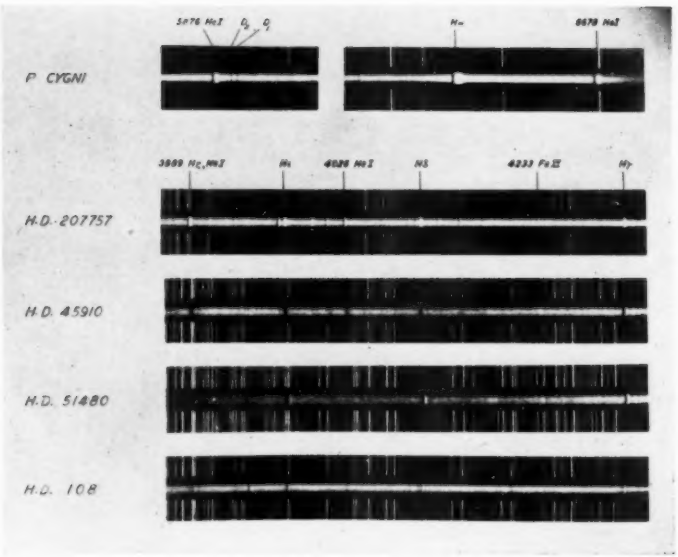
PRINTED IN CANADA

PLATE VIII



Specimens of Wolf Rayet Spectra

PLATE IX



P Cygni Spectra

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY
OF CANADA

Vol. XXXIV, No. 5 MAY-JUNE, 1940 WHOLE No. 294

ON THE PHYSICAL CHARACTERISTICS OF THE WOLF RAYET STARS AND THEIR RELATION TO OTHER OBJECTS OF EARLY TYPE

By C. S. BEALS

(with Plates VIII and IX)

SECTION I — THE WOLF RAYET STARS

Discovery and Early Observation. The first three examples of Wolf Rayet spectra, H.D. 191765, H.D. 192103 and H.D. 192641 were discovered visually by Wolf and Rayet[1] at the Paris Observatory in the course of one of the pioneering investigations of stellar spectroscopy. A number of further visual discoveries were made by Respighi,[2] Pickering[3] and Copeland,[4] while the Harvard objective prism plates revealed about forty additional examples. The first accurate wave-lengths of Wolf Rayet bands were determined by Campbell[5] working by visual methods in 1894. More recently the Wolf Rayet character of thirteen planetary nuclei was discovered and their spectra were described by Wright,[6] while further detailed investigations of Wolf Rayet stars have been carried out at Cordoba,[7] Harvard[8] and Victoria[9].

[1] *Comptes Rendus*, v. 65, p. 292, 1867.
[2] *Comptes Rendus*, v. 74, p. 516, 1871.
[3] *Nature*, v. 23, p. 604, 1881.
[4] *Copernicus*, v. 3, p. 206, 1883.
[5] *Astronomy and Astrophysics*, v. 13, p. 448, 1894.
[6] *P. Lick O.*, v. 13, Part VI, p. 193, 1918.
[7] Perrine, *Ap.J.*, v. 52, p. 39, 1920; *M.N.*, v. 81, p. 142, 1920.
[8] Payne, *H.B.*, nos. 834, 836, 843, 844, The Stars of High Luminosity, *Harvard Monograph*, No. 3.
[9] Plaskett, *P. Dom. Ap. O.*, v. 2, p. 346. Beals, *P. Dom. Ap. O.*, v. 4, p. 271, 1930; v. 6, p. 95, 1934; *M.N.*, v. 90, p. 202, 1929; v. 92, p. 577, 1932.

General Spectral Characteristics. The most conspicuous feature of Wolf Rayet spectra is the presence of emission lines of atomic origin having a breadth and intensity which distinguish them from all other permanent stellar spectra. In some of the best known examples the broad lines (more commonly referred to as bands) are from 60 to 100 angstroms in width and attain an intensity from 10 to 20 times that of the continuous spectrum on which they are superposed.

An equally important feature of these spectra, but one which is less immediately obvious on casual inspection, is the presence of absorption borders on the violet edges of the emission bands. These absorption borders are usually broad and ill-defined but they occasionally reach an intensity which makes them conspicuous features of the spectrum.

Observational aspects of Wolf Rayet stars are illustrated in Plate VIII which contains a number of typical spectra of this type and in Figure 1, where a number of typical band profiles are shown.

Atomic Origin of Bands. The earlier observers of Wolf Rayet spectra noted the presence of bands due to H, He I, He II, N III, O III, Si II, Si III, Si IV, C II and C III, although there were many bands that remained unidentified. Recently the work of Edlén[10] on the spectra of atoms of higher ionization potential has led to the identification of all but a few of the previously unknown bands with the atoms of C IV, N IV, N V, O IV, O V and O VI.

Classification. Attempts to classify Wolf Rayet spectra at first met with difficulties owing to the apparent impossibility of finding criteria of excitation which were consistent from star to star. These difficulties largely disappeared when it was discovered that the spectra were divided into two parallel sequences corresponding in one case to the presence of carbon and oxygen to the exclusion of nitrogen and in the other to the presence of nitrogen to the exclusion of oxygen and carbon. He I, He II and hydrogen are common to both sequences although hydrogen is weak and always blended with He II.

The reproductions of spectra in Plate VIII have been arranged to illustrate the comparative spectral characteristics of the two sequences which are referred to as the carbon and nitrogen sequences

[10] *Observatory*, v. 55, p. 115, 1932.

respectively. This figure also illustrates the system of classification recently adopted by the International Astronomical Union[11] to distinguish one sequence from the other and to indicate the progression in ionization which exists within each. In addition to the letter W to designate all stars of the Wolf Rayet class, the letter C or N is added to indicate, respectively, membership in the carbon or the nitrogen sequence. The carbon sequence has been divided into three and the nitrogen sequence into four classes, corresponding to successive values of the line-intensity ratio λ5411 He II/λ5875 He I. The two sequences appear to be roughly parallel as regards excitation and in their lower ranges they correspond to the degree of ionization found in absorption O type stars. The 56 stars for which adequate data exist are distributed as follows among the various classes: W5, 8; W6, 29; W7, 14; W8, 5.

Relation between Band Width and Spectral Type. In addition to the progression in ionization which exists within each sequence

TABLE I

Relation between Band Width and Spectral Type

Type	λ4440	(*a*) Carbon Sequence Ejection Velocity (Km/sec.) λ4786	λ5411	λ5696
WC6	1625	1315	1537	2410
WC7	872	882	975	1560
WC8	464	393	540	956

Type	λ4605	(*b*) Nitrogen Sequence Ejection Velocity (Km/sec.) λ4686	λ5411	λ5875
WN5	640	1997	1361	—
WN6	487	1599	1550	1815
WN7	141	735	530	735
WN8	—	637	520	785

[11] *I.A.U. Trans.*, v. VI, 1938.

there is also a parallel progression in band width, the wider bands being associated with earlier spectral type and vice versa. Numerical values of band width for a number of wave-lengths in each sequence are given in Table I. In accordance with the interpretation advanced in a later paragraph the widths are given in terms of the maximum velocity of ejection in km/sec., which corresponds to the edge of the band. The progression for the group of lines as a whole is somewhat more clearly marked for the carbon sequence but it may be noted that the line λ4605 in the nitrogen sequence undergoes a nearly five-fold increase in width in passing from WN7 to WN5.

General Interpretation of Wolf Rayet Emission. The emission bands of Wolf Rayet stars have been interpreted in terms of the continuous ejection of high-speed atoms from the stellar surface. As a consequence of this process of ejection the star is surrounded by a nebulous envelope of outward moving atoms somewhat resembling a miniature planetary nebula, and it is in this envelope that the emission bands are believed to have their origin. This interpretation rests upon three principal lines of reasoning which may briefly be summarized as follows.

1. Since Stark broadening is precluded by the low density of the upper atmospheric layers where all emission lines are believed to have their origin, the enormous widths of Wolf Rayet bands can hardly be accounted for except on the basis of some form of Doppler effect. Of the various possible forms of Doppler broadening such as stellar rotation, thermal agitation and convection currents, all except radial ejection of atoms are ruled out by the magnitude of the velocities required which are sometimes as great as 3000 km/sec.

2. In an envelope of outward moving atoms any observable absorption of the star's continuous spectrum must arise in that portion of the envelope between the star and the observer. Since this region corresponds to the maximum negative velocity in the observer's line of sight a satisfactory explanation is provided for the appearance of absorption borders on the violet edges of emission bands.

3. Wolf Rayet bands are strikingly similar to those appearing at certain stages in the development of novae where the ejection

hypothesis has long been regarded as established. While the establishment of the ejection hypothesis in the case of novae is based on arguments similar to those cited above, there are certain special phenomena associated with novae such as the appearance of successive shells, changes in the velocities of shells and the appearance of visible envelopes which provide observational verification of a kind not available for the Wolf Rayet stars.

Mechanism of Emission. The analogy already suggested between Wolf Rayet emission and that of planetary nebulae points to a similar mechanism operating in both cases to produce the emission lines. Zanstra[12] has presented what appear to be conclusive arguments demonstrating that the great intensities, relative to the nuclear continuous spectrum, of the majority of nebular lines can only arise as a result of the process of ionization and recombination. These arguments, presented to account for nebular emission, apply with equal force to the case of Wolf Rayet stars and in the discussion which follows it is assumed that a similar process is operating to produce Wolf Rayet emission.

Stratification of Envelope. Bowen[13] has pointed out an interesting consequence of the mechanism of ionization and recombination, namely the stratification of the envelope in which it occurs owing to the progressive absorption of ionizing radiation by successive layers of the nebular gas. In this type of stratification atoms of highest ionization potential are found nearest the central star where the ionizing radiation is most intense, while atoms of lower ionization can exist only in outer layers where the higher frequencies of the stellar radiation have been reduced in intensity by photoelectric absorption.

The beautiful observational verification of Bowen's prediction for the nebulae is well known. In accordance with prediction, the diameters of the monochromatic nebular images have been shown to be in inverse ratio to the ionization potential of the atoms responsible for the emission. This type of observational test is not available for the Wolf Rayet stars, but there are a number of observations which are more easily explained if it be supposed that bands due to atoms of different ionization potential originate in

[12] *P. Dom. Ap. O.*, v. 4, p. 209, 1930: *Zs. f. Ap.*, v. 2, p. 1, 1931.

[13] *Ap. J.*, v. 67, p. 1, 1928.

different parts of the nebulous envelope. These observations include the presence in the same spectrum of atoms of such widely different ionization potentials as N V (I.P. 97 volts) and He I (I.P. 24 volts). Another such observation is the existence of marked differences in width between bands due to atoms of different ionization potential. These differences are illustrated in Table II where velocities of ejection corresponding to observed band widths are given for a number of atoms appearing in successive stages of ionization.

The data of this table not only illustrate individual differences in band widths but they also demonstrate the existence of a general relationship between band width and ionization potential. In every case where successive ionizations of the same atom appear together in a spectrum the greater band width is associated with the smaller ionization potential. The conclusion to be drawn from this relationship is of considerable importance since it sheds light on a point which is discussed in considerable detail in connection with band profiles. If Bowen's picture of an envelope stratified according to ionization potential be accepted, then it follows that the atom is subject to an outward acceleration during the course of its

TABLE II

Band Width and Ionization Potential

(*a*) Nitrogen Sequence		Atom	He II	He I	NV	N IV	N III
		λ	5411	5875	4605	3483	4634
Star	Class	I.P.	54.2	24.5	97.4	77.0	47.2
H.D. 187282	WN5		1361	—	640	—	—
H.D. 192163	WN6		1550	1815	487	1235	—
H.D. 151932	WN7		530	735	141	—	930
H.D. 177230	WN8		520	785	—	—	645

(*b*) Carbon Sequence		Atom	He II	He I	C IV	C III
		λ	5411	5875	4440	5696
Star	Class	I.P.	54.2	24.5	64.2	47.7
H.D. 16523	WC6		1537	—	1625	2410
H.D. 192103	WC7		975	1290	872	1560
H.D. 184738	WC8		540	1075	464	956

motion through that part of the envelope responsible for the emission lines.

Analysis of Band Profiles. The principal interest attaching to the analysis of band profiles is the possibility which they offer of discovering the laws governing the velocities of ejected atoms.

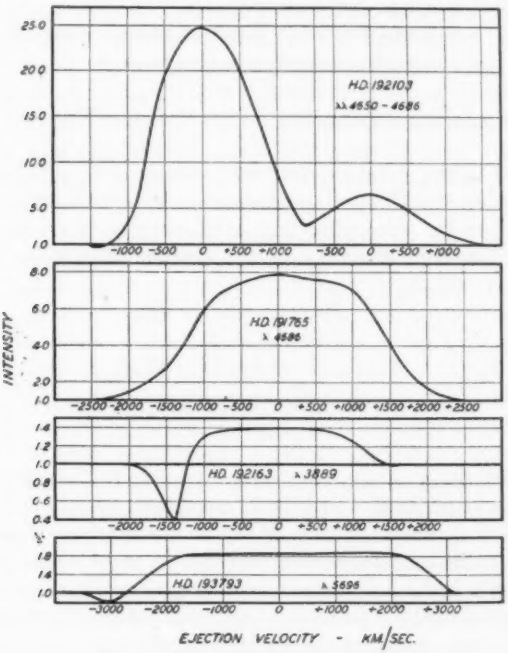


Fig. 1—Typical Wolf Rayet Profiles

Certain special cases of velocity distribution involving flat-topped bands were first treated at Victoria[14] but more comprehensive investigations of the general problems of band profiles have since been carried out by Gerasimovič,[15] Chandrasekhar[16] and Wilson[17].

[14] *P. Dom. Ap. O.*, v. 6, p. 111, 1934.
[15] *Zs. f. Ap.*, v. 7, p. 335, 1933.
[16] *M.N.*, v. 94, p. 522, 1934.
[17] *Ap. J.*, v. 80, p. 259, 1934, *Mt. W. Cont.* no. 500.

Unfortunately, while elegant solutions of the analytical and geometrical problems have been presented, success in their application to observed band profiles has so far been less complete than might be desired. The present status of the problem may be illustrated by reference to the formulae derived by Gerasimovič.

Let V = velocity of radial ejection
r = distance of emitting atoms from centre of star
u = velocity in observer's line of sight

then let $$V = r^{\alpha} \qquad (1),$$

where α is a constant depending on the law of acceleration

and let $$i(r) = r^{-\beta} \qquad (2),$$

where $i(r)$ is the emission per unit volume and β is a constant depending on the physical conditions under which emission takes place. Then by integrating $i(r)$ over surfaces of constant u the following family of profiles may be derived depending upon the values of α and β.

$$i(u) = 1 - u^{\gamma} \qquad (3),$$
$$i(u) = u^{-\gamma} - 1 \qquad (4),$$
$$i(u) = -\log u \qquad (5),$$

where $$\gamma = \left| \frac{\beta - 3 + \alpha}{\alpha} \right| \qquad (6).$$

The difficulties of applying these formulae to the interpretation of observed band profiles may be inferred from the relation between α, β, and γ in equation (6). Even in cases where a perfect fit enables γ to be unambiguously determined there exists no unique solution for α and β. In order to derive a value for α some assumption must be made regarding β and even under relatively simple conditions lack of knowledge concerning the relationship between density, dilution of radiation and emission per unit volume makes any assumed value of β subject to great uncertainty. The probable existence of stratification in the emitting envelope introduces additional complications into the problem and it may be questioned whether in any single instance it is possible (from a consideration of the shape of any one band) to be certain whether the acceleration of ejected atoms is positive or negative.

While the results of Gerasimovič have been used for purposes of illustration, similar difficulties are met with in applying the

formulae of Chandrasekhar and Wilson. Chandrasekhar has suggested that a way out of the difficulty might be found if it could be assumed that the relative dimensions of star and envelope are such that occultation by the star's disc plays an important role in the formation of the band profile. The asymmetrical profiles derived on this hypothesis make it possible to distinguish more definitely between positive and negative acceleration of ejected atoms. Unfortunately the fundamental assumption is of doubtful validity, while observational difficulties are encountered in the application of the theory. In every case where emission bands exhibit marked asymmetry they are accompanied by strong absorption borders on their violet edges, and since the absorption borders must be in part responsible for the asymmetry the interpretation in terms of theory remains uncertain.

Finally in addition to other causes for uncertainty in the interpretation of band profiles, the possibility of large scale turbulence due to localized outbursts on the star's surface cannot be entirely disregarded. There are many observations of early type spectra which find their readiest explanation in terms of turbulence and it would appear reasonable to expect turbulence to be at a maximum in Wolf Rayet stars owing to their high temperatures and the (assumed) lack of equilibrium between radiation pressure and gravity at their surfaces. It is accordingly possible that effects of this kind may exercise an influence of major importance in determining the profiles of many Wolf Rayet bands.

Temperature. From a study of spectrophotometric gradients Gerasimovič[18] has derived a mean temperature of 17,000° for eight Wolf Rayet stars. While there is every reason for confidence in the accuracy of Gerasimovič's measurements the resulting temperatures are improbably low for objects whose spectra represent the highest ionization known in stellar atmospheres. Since recent developments in the interpretation of such observations[19] have indicated that any temperatures derived from spectrophotometric gradients of early type stars are subject to considerable uncertainty, recourse must be had to some alternative method

[19]*H.C.*, no. 339, 1939.

[19]Woolley, *M.N.*, v. 94, p. 713, 1934. Pannekoek, *M.N*, v. 95, p. 529, 1935. Unsold, *Zs. f. Ap.*, v. 8, p. 225, 1934. Bierman, *Gott. Nach.*, no. 18, 34, 37.

based on considerations of ionization. Such an alternative method has been developed by Zanstra[12] to determine the temperatures of planetary nuclei and this method has been applied to the Wolf Rayet stars making use of Zanstra's well known equation

$$\int_{x_0}^{\infty} \frac{x^2}{e^x - 1}\, dx = \sum \frac{x^3}{e^x - 1} A_\nu,$$

$$x = \frac{h\nu}{KT}, \qquad x_0 = \frac{h\nu_0}{KT},$$

$$A_\nu = \int_0^{\infty} I_\lambda d\lambda,$$

where ν_0 is the ionizing frequency and I is the intensity of a point on the emission line profile (with the underlying continuous background removed) relative to the continuous spectrum in the neighbourhood of the line.

The results of temperature determinations for typical stars in each of the seven classes of Wolf Rayet spectra are contained in Table III. The figures range from 60,000° to 110,000°. The adopted temperature for each class, contained in the last column of the table, represents an estimate based on the values of the preceding column and adjusted to equalize the temperature differences from class to class. According to the theory on which the methods are based these temperatures are minimum values and the actual surface temperatures of the stars may be considerably in excess of those shown.

Absolute Magnitude and Stellar Diameter. Measures of interstellar line intensity made at Victoria[20] and Mount Wilson[21] provide estimates of distance for eleven Wolf Rayet stars. Additional distance determinations for thirteen planetary nuclei of Wolf Rayet type have been made available through the work of Berman[22] on

[20]Beals, *M.N.*, v. 96, p. 661, 1936.

[21]Merrill, Sanford, Wilson and Burwell, *Ap. J.*, v. 86, p. 274, 1937. *Mt. W. Cont.*, no. 576.

[22]*Lick O. Bull.*, no. 486, 1937.

galactic rotation. It is probable that the "interstellar" parallaxes are individually more reliable though the galactic rotation effect provides the fundamental basis for the scale of distance in each case. Absolute magnitudes derived from the usual formula $M=m+5+5\log\pi$ are given in Table IV. The planetary nuclei are placed in a separate part of the table to facilitate comparison.

TABLE III

Temperatures of W Stars

Star	Class	Atom	I.P. (volts)	Temp.	Adopted Temp.
H.D. 187282	WN5	N V	97.4	97,000°	95,000°
		He II	54.2	69,000°	
H.D. 192163	WN6	N V	97.4	90,500°	85,000°
		He II	54.2	71,000°	
H.D. 151932	WN7	N V	97.4	75,000°	72,000°
		He II	54.2	63,000°	
H.D. 177230	WN8	He II	54.2	60,000°	59,000°
		N III	47.2	56,000°	
H.D. 165763	WC6	O V	113.3	113,000°	110,000°
		C IV	64.2	92,000	
H.D. 192103	WC7	C IV	64.2	87,000°	90,000°
		C III	47.7	74,000°	
H.D. 184738	WC8	C III	64.2	72,000°	70,000°
			47.7	69,000°	

The means for the two groups indicate an absolute magnitude of +1.0 for the planetary nuclei and −2.8 for the eleven Wolf Rayet stars for which interstellar intensities are available. Since these eleven stars have a mean apparent magnitude of 7.6, a full magnitude brighter than the mean of 8.6 for all the Wolf Rayet stars exclusive of the planetary nuclei, it is probable that a value of −2.0 would more correctly represent the intrinsic luminosity of these stars as a class. The difference of three magnitudes between

TABLE IV

Absolute Magnitude and Diameters

(*a*) Planetary Nuclei

Star	Dist. Parsecs.	*m*	*M*	Spectrum	*T*	Diam. (x⊙)
N.G.G. 40	1220	11.3	+0.9	WC8	70,000°	0.43
I.C. 1747	4270	14.9	+1.7	WC6	110,000	0.22
I.C. 418	1800	10.8	−0.5	WC7	90,000	0.71
N.G.G. 6210	1720	11.7	+0.5	WC7	90,000	0.45
N.G.G. 6543	1080	11.2	+1.0	WN6	85,000	0.36
N.G.G. 6572	1230	12.0	+1.5	WN6	85,000	0.29
I.C. 4776	5830	15.0	+1.2	WC6	110,000	0.28
N.G.G. 6751	4030	13.3	+0.3	WC6	110,000	0.42
H.D. 184738	1050	10.0	−0.1	WC8	70,000	0.68
N.G.G. 6826	1050	10.7	+0.6	WN6	85,000	0.44
N.G.G. 6905	3870	13.9	+1.0	WC6	110,000	0.33
N.G.G. 7026	3020	14.8	+2.4	WC6	110,000	0.16
N.G.G. 5217	3060	15.0	+2.6	WN6	85,000	0.17

(*b*) Stars Without Visible Nebulosity

Star	Dist. Parsecs	*m*	*M*	Spectrum	*T*	Diam. (x⊙)
H.D. 16523	2100	10.0	−1.6	WC6	110,000	1.0
" 50896	750	6.6	−2.8	WN6	95,000	2.0
" 151932	1230	6.6	−3.9	WN7	72,000	3.9
" 165763	1200	7.8	−2.6	WC6	110,000	1.6
" 190918	1650	7.0	−4.1	WN5	95,000	3.5
" 191765	1230	7.8	−2.7	WN6	85,000	2.0
" 192103	1375	7.9	−2.8	WC7	90,000	2.0
" 192163	1120	7.4	−2.9	WN6	95,000	2.0
" 192641	950	7.9	−2.0	WC7	90,000	1.4
" 193077	920	8.0	−1.8	WN6	95,000	1.2
" 193793	1650	6.8	−4.3	WC6	110,000	3.5

the larger group and the planetary nuclei is probably real, although the data available do not point to any clearly marked difference in spectral characteristics between those Wolf Rayet stars which are surrounded by visible nebulosity and those which are not.

Diameters have been computed for the stars of Table IV making use of the temperatures and absolute magnitudes in conjunction with the formula[23].

$$\log D = \frac{5900}{T} - 0.2M - 0.02 + 0.5 \log (1 - 10^{-k/\lambda T}).$$

The last term of the right hand member of this equation is usually omitted, but it has been retained here because it assumes considerable importance for temperatures above 30,000°. Its inclusion reduces the computed diameters by one-half for stars in the neighbourhood of 100,000°. In the application of this formula it should be noted that departures from black body laws may lead to uncertainties of unknown amount in the results but it has been assumed that the values derived are of the correct order of magnitude. It is improbable that errors due to this cause would seriously affect discussions of the general relationships between Wolf Rayet stars and other objects of early spectral class.

The results of the computation in the last column of Table IV indicate a mean diameter of 0.38⊙ for the planetary muclei and 2.2⊙ for the ordinary Wolf Rayet stars. Adjustment to the mean absolute magnitude reduces the latter value to 1.5⊙ for the ordinary Wolf Rayet stars as a class.

These relatively small dimensions suggest a conclusion which may well be of fundamental importance in a study of the physical nature of the Wolf Rayet stars, namely, that these objects may have masses which are relatively small. The state of ionization shown by the spectra of Wolf Rayet stars of class W8 suggests that their temperatures are of the same order as those of absorption line stars of classes O7 and O8. The smaller diameters of the Wolf Rayet stars (inferred from their smaller absolute magnitudes) appear to demand correspondingly small masses since otherwise the resulting high value of surface gravity would constitute a condition unfavourable to the ejection of material from the stellar surface*.

[23]Russell, Dugan and Stewart, *Astronomy*, p. 732. Ginn and Co., 1927.

*Since this was written Wilson has determined complete orbital elements for a newly discovered binary star (H.D. 193576), one component of which is a Wolf Rayet star of type WN5. The minimum masses and spectral types of the two

Section II — The P Cygni Stars and the Supergiants of Class A

Discovery and Spectral Characteristics of the P Cygni Stars. P *Cygni* is a former nova which appeared in 1600 and was later distinguished by a remarkable series of irregular variations which ended about the year 1677 when the star settled down to an approximately constant magnitude of 5.0. The unusual character of its emission line spectrum was discovered on the Harvard objective prism plates and subsequent discoveries both at Harvard and elsewhere revealed that P *Cygni* was but one of a considerable class of stars which had certain peculiar emission line characteristics in common, although sometimes showing considerable diversity in other respects. The most extensive observations of this class of stars have been carried out by Merrill and a complete bibliography of all investigations of P *Cygni* stars prior to 1933 has been published by Merrill and Burwell.[24] Recent investigations of the star P *Cygni* include those of Struve[25] and Beals.[26]

The characteristic P *Cygni* line profile consists of an emission line in approximately its normal position bordered on its violet edge by a displaced absorption line. The general character of the profile bears some similarity to that of many Wolf Rayet and nova bands, the principal difference being that the P *Cygni* lines are much narrower and the intensity, relative to the emission, of the displaced absorption components is usually much greater.

Reproductions of a number of P *Cygni* spectra are shown in Plate IX. The spectra in this figure have been chosen not only to illustrate the general characteristics of the P *Cygni* type of profile, but also the considerable diversity which exists among stars of this type in the degree of development of the emission line spectrum.

---

components of the binary are as follows: Wolf Rayet star 9.74⊙, WN5. Absorption line star 24.8⊙ B1. The mass of approximately 10 times the sun, while definitely less than that of the absorption component is scarcely in accord with the above general suggestions regarding the masses of Wolf Rayet stars. I am indebted to Dr. Wilson for communicating this information in advance of publication.

[24] *Ap. J.*, v. 78, p. 87, 1933.

[25] *Ap. J.*, v. 81, p. 66, 1935.

[26] *M.N.*, v. 95, p. 580, 1925; *Observatory*, v. 57, p. 319, 1934.

Figure 2 contains a number of measured line profiles from the spectrum of P *Cygni*, the star in which this type of spectrum finds its most complete development. These profiles are accompanied by intensity and velocity scales showing the relative strengths and displacements of the emission and absorption components of each line. Perhaps the most significant feature of this array is the extent to which the lines of different atomic origin differ among themselves in their velocity displacements and in the relative intensities of their absorption and emission components.

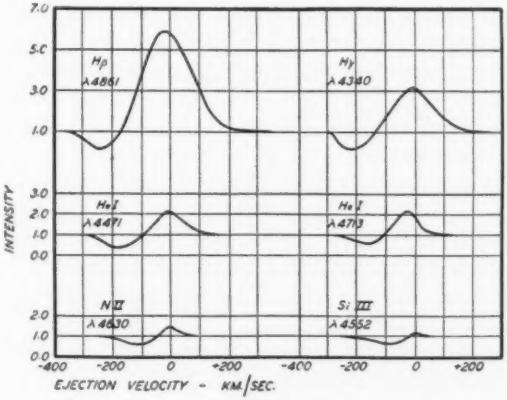


Fig. 2—P Cygni Profiles

In Figure 3 are shown several line profiles which differ in important respects from those found in the spectrum of P *Cygni*. These profiles are of the hydrogen lines in the spectrum of the star H.D. 190073* and in their more general aspects they are representative of similar profiles found in the spectra of a number of other stars. A careful scrutiny of the five lines of this diagram makes it clear that each profile is a blend, consisting of a broad underlying absorption line, similar to many typical hydrogen absorption lines in early type stars, with a narrower P *Cygni* profile superposed

*Comparison between spectra recently obtained at Victoria and earlier observations at Mount Wilson (*Ap. J.*, v. 77, p. 51, 1933) indicate that the star is a spectrum variable and that the profiles have undergone considerable changes.

upon it. In the profile of Hα the P *Cygni* component dominates the line and the broad absorption component is relatively inconspicuous. At Hζ the reverse is the case and the broad absorption line appears alone and is not visibly influenced by the P *Cygni* component.

An aspect of the profiles of Figure 3 which deserves particular attention is their similarity to the line profiles which characterize

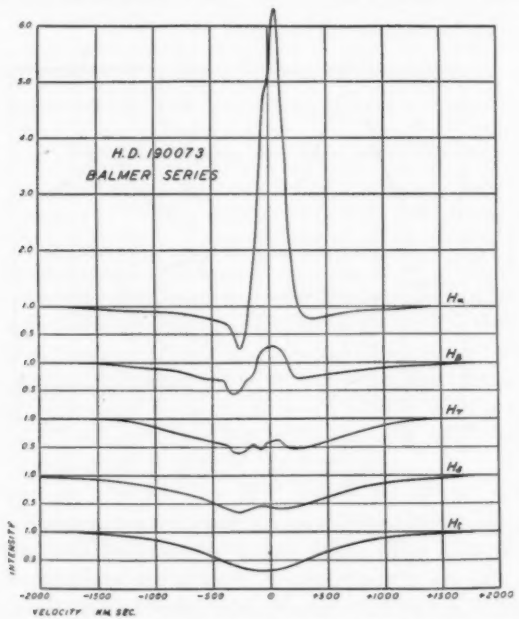


Fig. 3—Hydrogen Line Profiles H.D. 190073

stars of class Be. The typical Be profile consists of a relatively narrow emission line centrally superposed upon broad absorption, the emission in turn being centrally divided by a sharp and narrow absorption line. Without going into a more detailed discussion of the observations, it may be noted that during the investigation of P *Cygni* stars at Victoria practically every intermediate stage has

been observed between the symmetrical profiles just described as typical of class Be and the characteristic P *Cygni* profile of emission with absorption on its violet edge. It is accordingly very difficult to set up any arbitrary division line between P *Cygni* and Be stars and there are a few objects which could, with equal show of reason be assigned to either class.

Relation between P Cygni Stars and the Supergiants of Class A. Any discussion of the observational aspects of P *Cygni* stars would be incomplete without a reference to the close relationship which exists between these spectra and those of α *Cygni* and other supergiant stars of early A class. This group of stars, often referred to as of α *Cygni* type, have as their distinguishing characteristic the complete development of an absorption spectrum due to singly ionized metals such as Fe II, Si II, Ti II, etc. The narrowness of the metallic lines and their relatively great intensity distinguish this group of stars from others of early A type and this line quality is indicated in the Henry Draper classification system and in lists of stars compiled by Merrill[27] by the use of the letter "c" placed before the spectral class. These spectral characteristics are commonly associated with exceptionally high luminosity although there are apparently a few stars of α *Cygni* type whose absolute magnitudes are relatively low.

The relationship between the P *Cygni* stars and the cA stars is illustrated in Figure 4 which contains line profiles from the spectra of four stars of α *Cygni* type. For each star the profile of Hα is shown along with a number of characteristic lines due to ionized metals in the blue region of the spectrum. The upper three stars, H.D. 12953, α *Cygni* and H.D. 223385 are all of high luminosity (-6.1 to -7.5). The fourth star, H.D. 41511 (17 *Leporis*), is a peculiar variable of smaller absolute magnitude, possibly as low as $+1.0$ or less. In all but one case the line Hα appears as a typical P *Cygni* profile differing in no essential respect from those in spectra where the emission lines are more strongly developed. In the spectrum of H.D. 12953 the Hα line suggests a relationship with the Be class.

A further indication of close relationship between these two types of spectra (P *Cygni* and α *Cygni*) is found in the behaviour

[27] *Ap. J.*, v. 81, p. 351, 1935: *Mt. W. Cont.*, no. 512.

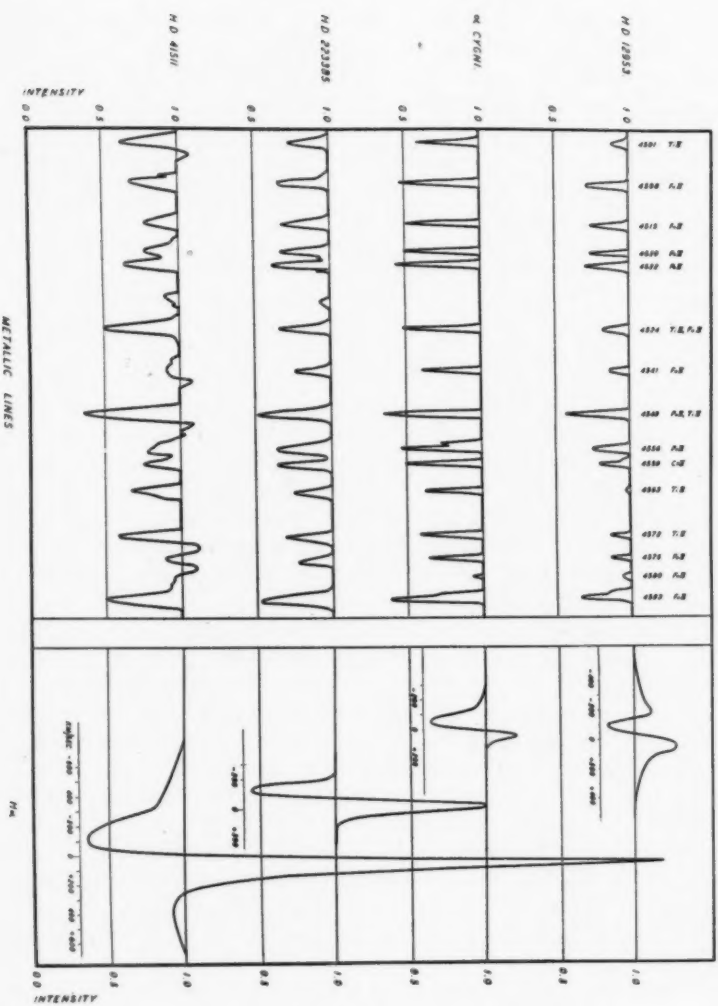


Fig. 4.—Profiles in α Cygni Type Spectra.

of certain stars of P *Cygni* type, notably the star H.D. 45910 which has been studied in detail by Plaskett[28] and by Merrill[29]. The spectral variations of this star correspond to a change in spectral type from B3 to A2. During the course of the change from class B to class A the star passes through a phase characterized by a complete development of the α *Cygni* type of spectrum. Later, as the cycle of variation is completed, the metallic lines fade and the star resumes its character as a P *Cygni* star of type B.

While not all stars of cA type have Hα emission associated with them, the evidence for physical association with the P *Cygni* objects seems too strong to be disregarded and the available data suggest that the α *Cygni* stars represent a continuation in class A of the P *Cygni* stars which are, in the main, associated with class B. The fading of the emission lines due to hydrogen, helium and other elements, and their replacement by an α *Cygni* absorption spectrum finds a logical explanation in the fall in temperature corresponding to the change from the earlier to the later class.

General Physical Interpretation of P Cygni Profiles. The general interpretation of P *Cygni* profiles in terms of the ejection of material from the stellar surface is similar to that already presented for the Wolf Rayet stars and it is unnecessary to repeat the detailed arguments supporting it. The relative narrowness of the P *Cygni* profiles is undoubtedly a result of the smaller velocity of ejection, while the smaller intensity of emission relative to absorption is probably in part a consequence of the smaller dimensions of the emitting envelope relative to the central star.*

In order to explain the complex profiles of Figure 3 it is necessary to assume that the broad underlying absorption lines are produced at a level corresponding to the reversing layer of an ordinary star where the density is sufficiently high for Stark broadening to be effective. The P *Cygni* component undoubtedly arises in higher levels and finds a logical explanation in terms of the ejection of material from the stellar surface. The absence of wings on the hydrogen lines of P *Cygni*, α *Cygni* and other similar stars points

[28] *P. Dom. Ap. O.*, v. 1, 1927.

[29] *P.A. Soc. Pac.*, v. 35, p. 303, 1923.

*This interpretation has been challenged by Chandrasekhar[16] who has advanced arguments in favour of small envelopes for Wolf Rayet stars.

to some definite physical difference between their atmospheres and those of stars like H.D. 190073 in whose spectra wings are prominent. Following a recent suggestion by Struve and Wurm[30] the explanation is probably to be found in the greater extension and greater optical thickness of the atmospheres of the former class of stars. This condition may result in the production of a continuous spectrum of considerable intensity in the rarefied outer layers of the atmosphere and this continuous spectrum may obscure absorption line wings produced in lower levels where the pressure is sufficiently high for Stark broadening to be effective. It is probable, though it has not yet been demonstrated with complete certainty, that these differences in atmospheric conditions are paralleled by corresponding differences in absolute magnitude.

Stratification of Envelopes. Reference has already been made to evidence which suggests that the atmospheres of Wolf Rayet stars are stratified according to ionization potential. Observations which suggest that a similar type of stratification exists in the emitting envelopes of P *Cygni* stars may briefly be outlined as follows:

1. Atoms with such widely different ionization potentials as Si I (6 volts) and He II (54.2 volts) have been observed in the same spectrum.

2. Absorption lines due to different atoms sometimes show marked differences in width and displacement.

3. The ratio of absorption to emission in P *Cygni* line profiles shows a marked correlation with ionization potential. This correlation is illustrated by the intensities of absorption and emission components of P *Cygni* lines listed in Table V. These intensities are of lines due to carbon, nitrogen, and silicon atoms which appear in successive stages of ionization in the spectrum of P *Cygni*. It will be seen that the relative emission line intensity increases in inverse ratio to the ionization potential and this may be interpreted as a consequence of the larger shells in which the atoms of lower ionization potential have their origin. The increasing intensity of emission relative to absorption is paralleled by increasing velocity of the absorption component of the P *Cygni* lines and this observation is in striking agreement with the similar

[30] *Ap. J.*, v. 88, p. 84, 1938.

increase in the widths of Wolf Rayet bands with decreasing ionization potential. The interpretation is in each case the same, namely, that the atom is subject to a positive acceleration in its motion outward from the stellar surface.

TABLE V

Intensities and Velocities of P *Cygni* Lines

Atom	I.P.	λ	Intensity Emission	(Km/sec.) Absorption	Velocity Emission	(Km/sec.) Absorption
C II	24.3	4267.14	7	4	−32	−154
C III	47.7	5895.80	1	1	+14	− 28
N II	29.5	4447.03	7	8	−14	− 95
	29.5	4601.49	26	20	−12	− 91
	29.5	4607.17	14	24	− 8	− 92
	29.5	4613.88	13	14	−12	− 87
	29.5	4621.40	15	16	−23	− 90
	29.5	4630.55	33	39	− 3	− 98
N III	47.4	4097.31	—*	9	—	− 47
Si II	16.3	6347.10	87	4	−23	−270
	16.3	6371.36	43	6	−19	−298
Si III	33.3	4552.61	10	32	+ 6	− 86
	33.3	4567.83	8	29	− 1	− 77
	33.3	4574.75	8	21	+ 5	− 78
Si IV	45.0	4088.86	0	19	—	− 32
	45.0	4116.10	0	18	—	− 33

*Emission obscured by Hδ.

Temperatures, Absolute Magnitudes and Diameters of P Cygni Stars. Data on temperature, absolute magnitude and diameter for 29 P *Cygni* stars are contained in Table VI. The scale of temperatures is based on a value of 30,000° for B0 from Zanstra's method and 11,000° for A0, the commonly accepted value for a star of this

TABLE VI

P *Cygni* Stars

(*a*) Galactic Stars

Star	Dist. Parsecs	*m*	*M*	Spectrum	*T*	Diam. (x⊙)
H.D. 108	1200	7.4	−3.0	O6	40,000	3.8
Comp. o *Ceti*	77	10.0	+5.6	B8	14,000	0.18
H.D. 12953	2500	5.9	−6.1	A2	9,000	71.0
H.D. 13841	1850	7.2	−4.1	B2	25,000	8.9
H.D. 14134	2350	6.7	−5.2	B2	25,000	14.8
H.D. 14143	2500	6.7	−5.3	B1	28,000	14.1
H.D. 14818	2180	6.2	−5.5	B1	28,000	15.5
H.D. 41511	38	5.0	+2.1	A0	11,000	1.1
H.D. 45910	800	6.7	−2.8	B3	22,000	5.4
H.D. 169454	1850	6.8	−4.5	B0	30,000	9.3
H.D. 190073	280	7.9	+0.7	A0	11,000	2.1
H.D. 190603	925	5.7	−4.1	B0	30,000	8.1
P *Cygni*	1010	5.0	−5.0	B1	28,000	12.3
α *Cygni*	576	1.3	−7.5	A2	9,000	135.0
H.D. 198478	1100	4.9	−5.3	B2	25,000	15.5
H.D. 207757	350	7.6	−0.1	B1	28,000	1.3
Comp. R. *Aqr.*	191	11.0	+4.6	B2	25,000	0.16
H.D. 223385	3500	5.6	−7.1	A2	9,000	112.0

(*b*) Stars in Large Magellanic Cloud

$T = 22{,}000°$ Distance = 34,480 parsecs

R.A. (1900)	Dec. (1900)	*m*	*M*	Diam. (x⊙)
h m				
5 5.8	−71° 03′	12.3	−5.4	17.8
5 14.0	−67° 34′	11.4	−6.3	26.9
5 14.4	−69° 28′	11.4	−6.3	26.9
5 14.7	−69° 38′	11.6	−6.1	24.5
5 18.9	−69° 21′	9.0	−8.7	81.3
5 28.5	−69° 04′	13.3	−4.4	11.2
5 29.0	−69° 13′	12.2	−5.5	18.6
5 36.2	−69° 44′	10.5	−7.2	40.7
5 37.2	−69° 26′	11.3	−6.4	28.2
5 37.5	−69° 33′	11.1	−6.6	30.9
5 41.0	−69° 26′	12.0	−5.7	20.4

spectral class. Intermediate values are assigned on the basis of spectral class. For H.D. 108, the only star of type earlier than B0, the temperature of 40,000° has been derived from the intensity of HeII λ4686 by Zanstra's method.

The absolute magnitudes depend mainly on distances derived from interstellar lines and on the distance of the Large Magellanic Cloud as determined from the period-luminosity relation. One trigonometric parallax (for 17 *Leporis*) has been included, while the distances of the two dwarf stars, the Companion of *o Ceti* and the Companion of R *Aquarii*, depend upon spectroscopic parallaxes of the M type stars with which they are associated.

The eleven P *Cygni* stars in the Large Magellanic Cloud form an important part of the data and it has often been assumed in the past that the absolute magnitudes of P *Cygni* stars are restricted to values in the immediate neighbourhood of −6.3, the mean for this particular group. Actually, and this point was particularly emphasized by the Harvard observers, the stars observed in the Large Magellanic Cloud were limited to apparent magnitude 12.8 or brighter, and if the observations were extended to fainter stars the mean would probably be lowered and the spread in absolute magnitude considerably increased.

For the galactic stars the mean intrinsic luminosity is −4.3 mags. and this becomes −4.6 if three stars fainter than absolute magnitude zero are omitted. One of the most surprising features is the presence of the Companions of *o Ceti* and R *Aquarii* whose low luminosities (+5.6 and+4.6) and early spectral types (B8 and B2) suggest that they may belong in the sub-dwarf class.* These two stars, which are variable in light and spectrum and resemble P *Cygni* only at times, have been observed by Joy[31] and Merrill[32] respectively. Dr. Joy, in a private communication, has recently expressed doubts as to the P *Cygni* character of the Companion of *o Ceti*. The P *Cygni* characteristics of the Companion of R *Aquarii* appear to be beyond question.

The diameters have been calculated from the temperatures and

*The sub dwarfs, so designated by Kuiper, are intermediate in absolute magnitude between the white dwarfs and the main sequence.

[31] *Ap. J.*, v. 63, p. 281, 1926; *Mt. W. Cont.*, no. 311.

[32] *Ap. J.*, v. 81, p. 312, 1935; *Mt. W. Cont.*, no. 513.

absolute magnitudes on the basis of the formula already quoted and are given in the last column of Table VI. The mean for the P *Cygni* stars as a class is of the order of $20\odot$, while that for the three α *Cygni* stars which have been included is considerably higher. As in the case of certain Wolf Rayet stars already discussed, the very small diameters found for the two dwarf stars appear to require correspondingly small masses in order to preclude excessive values of surface gravity.*

Section III — General Discussion

Possible Existence of a Separate Sequence. The stars discussed in the two preceding sections have been grouped together for purposes of investigation because they exhibit in common a peculiar type of emission line profile which has been interpreted in terms of the ejection of gaseous material from the star. Although these stars cover a range extending from class A to the earliest known spectral types and although they comprise three groups of stars having superficially little resemblance to one another, this common feature of their emission line spectrum has pointed to some fundamental physical relationship between them. Evidence for the existence of such a physical relationship has been strengthened by detailed studies of their spectra and the observations at present available appear to find their most satisfactory explanation in terms of a definite sequence of stellar spectra, following a different course from the main sequence and separated from it by some physical characteristic which is not yet fully understood. Such a sequence would comprise the Wolf Rayet stars, the P *Cygni* stars and some, if not all, of the supergiants of class A.

In discussing the possible existence and the physical implications of such a sequence, it should be pointed out that the number of objects involved is relatively small and many of the spectra which might have a bearing on the question have not been observed in sufficient detail. Perhaps the most serious deficiency in the data is the lack of slit spectra for the important group of P *Cygni* stars in the Large Magellanic Cloud. This is particularly to be deplored because the P *Cygni* group is very poorly represented in the North-

*See footnote, p. 181, on lack of confirmation of this conclusion for W stars.

ern Hemisphere. Many of the stars listed show the P *Cygni* characteristic very faintly and the number of stars having emission spectra with a development at all comparable to that of P *Cygni* is very small indeed. In addition there are numerous Wolf Rayet stars in the Southern Hemisphere which have not been adequately observed, while the faintness of the planetary nuclei has made detailed observations impossible for all except a few objects of relatively bright apparent magnitude. As a consequence, while it has been assumed that the objects available for observation are sufficiently representative of the stars as a whole, it is possible that the general picture here presented would be somewhat altered if the observations were more complete.

The relationship between the P *Cygni* stars and the A type supergiants has already been discussed and the observations appear to leave little doubt of the close physical connection between them. For the purposes of this discussion it is accordingly assumed that they represent successive stages of a physical sequence and that the distinction between them is mainly one of temperature.

Similar grounds for relating the Wolf Rayet and the P *Cygni* stars are found in the fact that each group apparently represents the only logical analogue of the other in the corresponding earlier or later spectral class. Considering the matter from the point of view of the width of Wolf Rayet bands we may note that the three-fold decrease in the velocity of ejection (1500 km/sec. to 500 km/sec.) in passing from class W6 to W8 leads to the prediction of a group of emission line objects of later spectral type with ejection velocities of the order of 100 to 300 km/sec., a description which accurately fits the P *Cygni* stars. The progression in excitation is also consistent with the idea of a physical connection between the Wolf Rayet and P *Cygni* stars. In P *Cygni*, N II and He I are prominent, N III is present, while He II has not yet made its appearance. In WN8, N II has faded out, He I is becoming weaker. N III is the most prominent feature of the spectrum while He II is represented by lines of considerable strength. A further connection between the two groups is found in the fact that there are lines in the spectra of certain stars of classes WN7 and WN8 which bear such a close resemblance to the typical P *Cygni* profile that in the absence of other Wolf Rayet stars with which to

associate them, these objects would undoubtedly be classed among the P *Cygni* stars.

The P *Cygni* stars appear to be more closely related to the nitrogen than to the carbon sequence though some lines due to carbon and oxygen appear in P *Cygni* spectra.

Analogy with Successive Stages of Typical Nova Spectrum. The association in a single sequence of the Wolf Rayet stars, the P *Cygni* stars and the stars of α *Cygni* type receives additional support from the similarity of their spectra to successive stages in the spectra of galactic novae. It is well known that the spectrum of a nova in the vicinity of maximum passes through a stage during which the spectrum strongly resembles that of α *Cygni*. Shortly thereafter when emission first makes its appearance the lines often show an equally striking resemblance to those of P *Cygni* and consist of narrow emission with strong absorption borders on the violet edges. Later, in the broad band stage, the analogy with Wolf Rayet spectra is too well marked and familiar to require comment.

The similarities to the novae cited above are not confined to the character of the line spectrum but are shared by the corresponding values of temperature and diameter. The parallelism between these related physical characteristics is shown in Figure 5. Temperatures have been plotted against diameter for the stars of Tables IV and VI as well as for a number of c type stars of early A and late B class for which interstellar line intensities are available. The resulting distribution is compared with the course followed after maximum by Nova *Lacertae* 1936. The temperatures used for the nova are those derived from emission line intensities. If colour temperatures are employed the entire curve is shifted to the left but its general character remains unaltered. While the curve for a single nova has been used for purposes of illustration, Nova *Lacertae* is typical of galactic novae as a class and there can be little doubt that the heavy line drawn through the points of the diagram is roughly parallel to the normal course of nova development.

Speculations on the Origin and Evolution of Stars in the Sequence. Any speculations on the origin and evolution of stars represented in this diagram are necessarily coloured by the analogies with the novae which have just been described. The first and most obvious

suggestion which presents itself is that these stars may have their origin in nova activity. Apart from the general similarities to novae already mentioned, there are certain additional data which lend support to this hypothesis. The first is that a number of old novae, in particular Nova *Persei* 1901 and Nova *Aurigae* 1891, which have passed through their cycles of variation and have settled

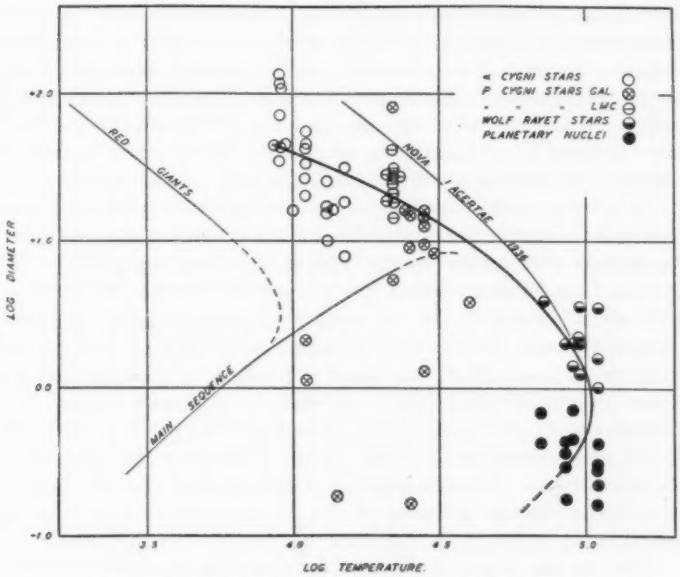


Fig. 7.—Relation between Temperature and Diameter.

down to approximately constant magnitudes, have spectra which strongly resemble those of Wolf Rayet stars.

Another piece of evidence which is probably of even greater significance is found in the history of P *Cygni*. This star is a former nova which has, apparently, found a position of equilibrium at a phase which is unstable for most novae. This remarkable circumstance considerably lessens the difficulties attending the hypothesis of a nova origin for the stars of Figure 5. If it could be assumed

that the exceptional nova may find a position of equilibrium at any point along its course, then the entire sequence, including α *Cygni*, P *Cygni* and the Wolf Rayet stars could be satisfactorily explained. Although the hypothesis of a nova origin for these stars has many attractive features, it is in rather definite conflict with certain recently advanced theoretical ideas on the origin of novae. It has been pointed out by a number of investigators that the amount of energy emitted during a nova outburst is too small to be regarded as the result of any major permanent change in the diameter or internal structure of a star. As a consequence a nova would be expected to have much the same physical characteristics before and after outburst and the approximate equality in the absolute magnitudes of a number of recent novae before and after outburst has frequently been cited in support of this view.

While the validity of these arguments cannot be denied, it may be pointed out that the establishment of a general rule, followed by the majority of novae connot entirely rule out exceptional behaviour in individual cases. In this connection the star P *Cygni* is of special interest. As has already been pointed out, the spectrum of this star (Beq) and its absolute magnitude (-5.0) suggest an unusual nova which has found a position of equilibrium at a phase (near maximum) that is unstable for ordinary novae. Unfortunately the pre-maximum magnitude of P *Cygni*, the particular datum most needed to shed light on the hypothesis outlined above, is not available. As a consequence it appears that the only hope of providing a definite solution of this fascinating problem is to be looked for in future observations of unusual stars of this kind.

Next to the origin of these stars, the most interesting subject which presents itself is the subsequent course of their evolutionary development. Unfortunately, this is a subject on which little can be said that goes beyond the stage of pure speculation. Many of the observations would be satisfactorily explained by supposing that an A type supergiant follows the same course as a nova after maximum, decreasing in diameter, increasing in temperature and becoming first a P *Cygni* and then a Wolf Rayet star. Alternatively, there are other observations, in particular the similarity between the P *Cygni* stars and the absorption line B stars, which would be more consistent with the idea that secular changes in the stars

correspond to a vertical displacement on the diagram of Figure 5. At present it is scarcely possible to do more than express the hope that theoretical studies of stellar structure may eventually make it possible to decide among the various alternatives.

In conclusion, there is one point that should be especially emphasized since it may have a bearing on some of the more general problems of stellar evolution; that is the lack of any clearly marked boundary between the emission line objects studied in this paper and the absorption line stars of early type which are commonly associated with a more normal phase of stellar development. In so far as the present observations are able to decide, it appears that the two types of stars shade into one another without any indication that they are objects of fundamentally different character. As a consequence it is necessary to consider the possibility that any conclusion which may eventually be reached as to the origin and the course of evolution of the stars of Figure 5 may find an application in explaining the origin and the position in the stellar sequence of many other early type stars.

Dominion Astrophysical Observatory,
Victoria, B.C.
Feb. 15, 1940

THE WORK OF THE MOUNT WILSON OBSERVATORY*

WALTER S. ADAMS, *Director*

FREDERICK H. SEARES, *Assistant Director*

THE work of the Observatory during the past year may for convenience be listed under three main headings: the sun and the solar system; the stars of our stellar system and the material which lies between them; and the extragalactic nebulae—more or less fully developed systems of stars which lie far outside our system, dotted throughout space like islands out to the limits reached by our largest telescopes. This observable portion of space has at present a radius of roughly half a billion light-years. It is filled with matter in almost every conceivable form, stars, clusters, organized stellar systems like our own, clusters of systems, finely divided cosmic dust, coarser material such as strikes the earth in the form of meteorites, and huge volumes of tenuous gas, often shining through excitation from a neighbouring star. In this complex aggregation the star is the most important unit, for it is a self-contained machine giving out great quantities of light and heat, probably maintained through atomic transformations in the material of which it is composed. With the single exception of the sun, however, the stars are so extremely distant that we must depend upon the sun itself and the changing phenomena of the disc for much of our information regarding stellar processes.

As a star the sun is of very moderate size and brightness, but it is typical of an immense number of stars in our system having the same temperature and doubtless very similar physical conditions. Since it is the source of life and heat for the whole planetary system, every important event upon it is of importance to the earth. So from every point of view the study of the sun is fundamental to astronomy, and it has always occupied place in the work of the Observatory.

*This general review of the work of the Mount Wilson Observatory is taken from the Carnegie Institution of Washington *Year Book* No. 38, for the year 1938-39.—*Editor*.

The Mount Wilson records of the state of the sun's surface, now reaching back more than 30 years, form an exceedingly valuable collection of material for reference and statistical studies, which is frequently consulted by astronomers from other parts of the world.

During the past year the sun has been in an exceptionally active state, and sun-spots have been large and numerous. The sun-spot activity has been at least as high as in 1937, and judged by a well-known index, the Wolf number, the month of July, 1938, was the most active month in the past 68 years. Although the maximum of the 11-year cycle of sun-spot activity has almost certainly passed, it is clear that the present maximum is of the broad type in which two or three successive years are characterized by nearly equal numbers of spots.

Since the discovery of magnetic fields in sun-spots by Dr. Hale in 1908, observations of the strength and direction of these fields have been continued regularly at Mount Wilson. The remarkable discovery of the reversal of sign of the field with the spot-cycle, first suspected in 1912 and confirmed in 1923, has been borne out fully by the observations of the present cycle; and a notable contribution to the study of this fundamental phenomena in solar physics was the publication by the Institution in 1938 of the magnetic classification of 2,174 spot-groups observed in earlier years by Hale and Nicholson.

The high state of solar activity has also favoured investigations of the spectrum of sun-spots, and by observing suitable spots with specially designed apparatus the range in wave-length over which such studies can be made photographically has been extended more than 30 per cent. Further, the occasional brilliant outbursts of light occurring in the sun's atmosphere near sun-spots, which in recent years have been found to produce magnetic storms upon the earth and radio fadeouts, are naturally more frequent during periods of high sun-spot activity. Eighteen such disturbances have been studied in detail, with especial reference to the time and duration of the outburst and the nature of the radiation given out by these regions of intense local activity.

Many other solar researches have been continued or completed, bearing on such varied problems as the number of the small, bright granulations visible on the surface of the sun, for which a photo-

graphic study gives for the whole sun of 950,000; the change in the intensity of the sun's radiation across its disc; the amount of ultraviolet light given out by the sun; and the intensity of the light of a sun-spot relative to that of the sun in different colours of the spectrum.

An instrumental development of interest is that of a photoelectric amplifier by means of which the amount of light in the spectral lines relative to that in the continuous background of the solar spectrum can be measured directly without the complications introduced by the photographic process. These relative intensities are basic data for a whole series of problems relating to the composition and state of the sun's atmosphere. Especially interesting is the reconstruction of the 60-foot tower telescope, which after 30 years of use has been rebuilt in such a way as to permit uninterrupted observations and the automatic registration of many solar phenomena. A synchronous motor drive with a mechanical speed change has been supplied and also a photoelectric guiding control which automatically corrects all displacements of the sun's image from its normal position.

When we pass from observations of the sun to those of planets and satellites in our solar system, an outstanding result is the discovery by Dr. Nicholson in July, 1938, of two additional satellites to the planet Jupiter, bringing the total number in this complicated system to eleven. Satellites X and XI are extremely small bodies, among the smallest known within the solar system, with diameters calculated at 15 and 19 miles, respectively, but they attract attention both because of their motions and because of the question of their origin. Whether they once formed a part of Jupiter or were captured by the great planet is a problem of exceptional interest.

Studies of the surface features of the moon have been in progress for several years under the charge of Dr. F. E. Wright of the Geophysical Laboratory of the Institution. The difficult but interesting question of the material composing the moon's surface has received a fairly positive answer. It cannot be exposed solid rock, but must be porous like pumice or light dust, which quickly loses the heat which it receives from the sun. Much of the evidence for this conclusion is derived from a comparison of the quality of the light (polarization) reflected from the moon's surface with that from

selected terrestrial materials. In addition to such observations, the moon has been photographed at brief intervals during an entire lunation. Studies of the numerous negatives thus obtained by stereoscopic projection and other means has contributed data needed for the preparation of an adequate topographical map of the moon.

In the vast field of the stars the investigations of the year have been many and varied. They range from determinations of distances, motions, and brightness of the stars to studies of the distribution of light within the lines of their spectra and estimates of the relative proportions of the different elements composing them. A few of these studies may be mentioned as illustrations.

The luminosity of a star, the actual amount of light it gives out, is a matter of great importance in physical astronomy. It may be detremined readily if the distance of the star is known, or by a study of its spectrum, or, in the case of certain stars whose light varies, from the period of light-variation. Further, for groups of stars the average luminosity may be obtained by calculations based upon their motions across the sky and toward or away from the earth. All these methods have been used in recent work at Mount Wilson. Of especial interest is the discovery of some stars of remarkably low candle power; several of these give out less than one ten-thousandth as much light as the sun, and one or two as little as one fifty-thousandth. At the other extreme, the average output of the most luminous stars, which have temperatures of the order of 20,000°C., is about 30,000 times that of the sun. The quantity of light sent forth by the sun is, therefore, roughly midway between that of the faintest and that of the most luminous stars.

The fact that our galaxy, the great system of stars to which our sun belongs, is in rotation, although long suspected, has been proved within recent years. Various determinations of the constants of this motion have been made; the most recent one, by Professor Joy, utilizes the fainter members of a class of very distant variable stars. The distance to the centre of rotation is found to be about 33,000 light-years; the circular orbital velocity of the sun, about 300 kilometers per second; and the period of revolution of the sun about the centre, 207,000,000 years.

Observations of the spectra of stars have been too numerous to

mention in detail. Of especial interest are the studies of the analyzed light of variable stars of several different classes, of stars showing bright lines in their spectra, of the very dense stars of high temperature but low luminosity known as "white dwarfs", and of some of the brighter stars which have been investigated with spectrographs more powerful than any hitherto available for stellar observations. Accurate measurements of the intensities of the spectral lines with the microphotometer are yielding valuable data on the temperatures and atomic constitution of all these objects.

Lying between the stars, especially in the neighbourhood of the Milky Way, are great quantities of finely divided cosmic dust involved in a stratum of interstellar gas. The dust affects different colours differently, scattering the blue and violet light which seeks to penetrate it much more than it does the red light. As a result, the light passing through these clouds of cosmic dust is reddened in colour, and the thicker the clouds, the greater the reddening. Such a cloud reddens appreciably the brighter stars in the vicinity of the North Pole. It has a thickness of about 1000 light-years and its nearer edge is only some 200 light-years distant. Another investigation of stellar colours, which now includes nearly 1500 stars measured with a photoelectric cell, shows that even some of the brighter regions in the Milky Way would appear twice as bright were no obscuring material present. A second important conclusion is that the interstellar gases, which produce definite lines superposed upon the spectra of many of the distant stars, are closely associated with the cosmic dust. The gases as well as the dust occur throughout a widely extended stratum, but the distribution of both is highly spotted and irregular.

The narrow lines produced by the atoms of absorbing interstellar gases are themselves a fruitful field of research. Investigations at Mount Wilson during recent years have more than doubled the number of such lines and added three more elements to those known to exist in interstellar space. Two studies have dealt with the physical state of these gases and the distribution of the gaseous clouds, and a third has resulted in a new determination of the abundance of the electrons and atoms of the identified elements. Sodium is found to

be some 30 times as abundant as calcium and several thousand times as abundant as titonium.

Recent discoveries of supernovae have centered attention on these extraordinary stars, which burst forth from quiescence and quickly attain a luminosity of a hundred million or more times that of the sun. They are observed occasionally, here and there in the multitudinous remote stellar systems; but within any single system they usually appear only at intervals of hundreds of years. Although no such outburst has been noted in our own system for several centuries, the so-called Crab Nebula in the constellation of Taurus is the remnant of a supernova which appeared in that part of the sky in the year 1054. Much stronger evidence of identity has been found in the expansion of the nebula, which was discovered some years ago. Recent measurements of changes within the nebula fit approximately the date of the beginning of the expansion, which agrees as well as could be expected with that of the outburst of the nebula.

With the discoveries of the past year, made mostly at Palomar Mountain by Dr. Fritz Zwicky of the California Institute of Technology, the total number of known supernovae has risen to 30. The analysis of the light of several of these stars shows that their spectra are remarkably similar and undergo similar changes as the light diminishes and fades away. In general the spectrum consists of a series of very broad bright bands, the width of which gradually decreases for about two weeks after the star has reached its maximum brightness and then remains constant. A noteworthy fact is the appearance at an early stage of a slowly but steadily increasing displacement toward the red, of the bands in the blue region of the spectrum, which in one instance was followed for nearly a year. The cause of the displacement and even the identification of the bands are as yet quite uncertain. In fact, the whole question of the interpretation of the spectra of supernovae is still an unsolved problem.

The more comprehensive studies of extragalactic systems, which constitute the third great field of investigation, have dealt with classifications according to the sequence of nebular forms; with surveys of the number of nebulae required to define more accurately the zone of avoidance within which the nebulae are hidden by clouds of cosmic dust; with the light-curves as well as the spectra of super-

novae; with the motions and rotations of nebulae, and the motion of our system of stars relative to the nebulae. Intensive observation of two faint systems of stars discovered at the Harvard College Observatory in the constellations of Sculptor and Fornax show them to be systems of comparatively low luminosity, located at distances of 300,000 and 600,000 light-years. They probably belong to the local group of extragalactic nebulae of which our stellar system is a member.

Future work on the structure and dynamics of extragalactic systems will be considerably influenced by the discussions of a conference held at the Observatory in June 1939. Both theoretical and observational investigators took part, among them Dr. Lindblad, Director of the Stockholm Observatory, Dr. Oort of the Leiden Observatory, and Dr. Mayall of the Lick Observatory, as well as members of the Observatory staff. With a large amount of photographic and spectroscopic evidence available for reference, working hypotheses could be reviewed and programs of observation effectively planned. The urgent need is a more detailed spectroscopic analysis of the light of distant systems, an investigation now to be attempted with improved instruments and photographic plates.

Almost every physical investigation of the sun or stars requires at some period of its interpretation the assistance afforded by data acquired under controlled conditions in the laboratory. This is especially true of studies of spectra or of radiation in general. As an illustration, we cannot determine the relative numbers of atoms of the different elements present in the atmosphere of the sun or a star unless we know certain factors which govern the numbers of atoms contributing to the formation of related lines in a spectrum. The evaluation of these factors is a laboratory undertaking, and experiments now under way demonstrate again the vital part played by the electric furnace and other laboratory equipment in solving stellar problems. In fact laboratory investigation is the first step in unravelling the complicated spectra which provide such a wealth of information regarding conditions in the stars.

An essential part of the Observatory's work, whether at the telescope or in the laboratory, has always been the adaptation and development of auxiliary apparatus which would contribute to the

success of the observations. The new equipment of the 60-foot tower telescope has already been mentioned. Other instances are improvements in diffraction gratings and in the design of spectrographs. The remarkable results attained by Professor R. W. Wood and others in concentrating so large a part of the light from a diffraction grating in any desired order has made the grating a strong rival of the prism in spectroscopic observations of faint light-sources. During the construction of the new ruling machine in the Observatory's shops, which is now well advanced, much experimental work is being done on different types of ruling surface and on methods of shaping the diamond ruling points so that the concentration of light will meet specified requirements. The principle of the Schmidt telescope, which was devised only a few years ago, is finding wide application in cameras for spectrographs. Its important features are great light-gathering power and sharp definition over a large field. Two such cameras, constructed for spectroscopic observations at the 100-inch telescope, present the extremes in this type of design. One utilizes a 36-inch mirror with a focal length of 114 inches; the other, with an aperture of about 2 inches, has a focal length of only 1.3 inches. Both have been designed to obtain specific results—spectra of bright stars on a very great scale, and spectra of objects so faint that scale must be reduced to the lowest limit permissible.

REVIEW OF PUBLICATIONS

The Pinpoint Planetarium, by Armand N. Spitz, with drawings by G. Carter Morningstar. Text, 86 pages; charts, 24; 10 x 8 inches. New York, Henry Holt and Co.; Toronto, Oxford University Press. Price $2.00.

Throughout the years much ingenuity has been expended in endeavours to assist the beginner to locate the constellations and identify the stars in them. For that purpose charts of the sky and instruments of various forms are continually being devised, which shows that there are many persons who are desirous of becoming acquainted with the heavens and other persons who are willing to help them do so. The thought of financial return hardly ever is entertained. The present production is a worthy addition to this desirable work and it has some new features.

The pretentious planetariums which have come into prominence in recent years provide a dome within which the visitor sits, and the stars are shown on it very realistically. In this book there are twenty-four simple charts, two for each month, which are to be removed; and then, with scissors and paste by following easy instructions, they are shaped into hemispheres. By means of a pin perforations are made in them at the proper places, and then when held up before a window or a lamp they give a good notion of the sky. If the young seeker after knowledge studies the suitable hemisphere for the occasion for half an hour before he goes out of doors to view the sky he will recognize the actual constellations and their stars much more readily.

After the observer has studied the sky for an hour he should turn to that section of the book devoted to the portion of the sky to be seen at this time and read interesting information about the stars he has just observed.

The positions of the planets during the years 1940-1945 are given, thus allowing them to be recognized when a star is seen which is not on the paper hemisphere.

The book is well designed and quite attractive. The author is an accomplished amateur astronomer with a telescope in a Philadelphia suburb, and is associated with the Franklin Institute.

C. A. C.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Death of Dr. W. E. Harper.

Dr.W. E. Harper, Head Astronomer of the Dominion Astrophysical Observatory, Victoria, B.C., died on Tuesday, June 4th, after a long illness. Dr. Harper was President of the Royal Astronomical Society of Canada in the years 1928 and 1929, and for several years has been an associate editor of this Journal. An account of his life and work will appear in the July-August number of this publication.

The Mirror for the Radcliffe Telescope.

For some time the dome and mounting of the 74-inch reflector of the Radcliffe Observatory have been in place in South Africa. Delays were encountered in securing and figuring the disc for the main mirror. We now learn that the figuring was unfinished at the outbreak of the war, and Sir Howard Grubb, Parsons and Co., the makers, have been unable to continue work on it. It has, for the last few months, remained buried by sandbags in a pit at Newcastle-on-Tyne. The Cassegrainian spectrograph has also remained uncompleted.

F. S. H.

MEETINGS OF THE SOCIETY

AT VICTORIA

January 24, 1940.—The first regular meeting of the Victoria Centre of the R.A.S.C. for 1940 was held in the Y.W.C.A. Parlours on Wednesday, January 24. At 8.10 p.m. the President, Mr. Robert Peters, called the meeting to order. Minutes of the previous meeting were read and approved and the librarian, Miss Hailstone, briefly mentioned Dr. Chant's book, "Our Wonderful Universe", a revised and enlarged edition of which is expected soon. It was announced that astronomical radio talks were being given on Mondays at 7.00 p.m. over radio station CFCT and were to continue until the middle of April. Mr. Peters outlined current phenomena and mentioned the asteroids as well as the unusual grouping of the planets late in February. The president complimented Dr. J. A. Pearce on his recent election to the Presidency of the Royal Astronomical Society of Canada and then called upon him to be the speaker of the evening.

The subject of the lecture was "Seismology and the Structure of the Earth". The history of seismology was first discussed. References to earthquakes in the Bible, the classes of earthquakes listed by Aristotle, the first seismoscope by Choko, Mitchell's work following the Lisbon earthquake of 1755, and Milne's work in Japan and in England about 1880 in developing seismographs and in interpreting seismograms were mentioned. Dr. Pearce defined the P- and S-waves, which pass through the earth, and the L-waves, which follow the surface of the earth, and showed how, by studying the theory of elasticity, the distance from the centre of an earth shock could be determined at any station. As an example of a typical earthquake, the Kwanto, Japan, earthquake of Sept. 1, 1923, was discussed and seismograms obtained at Victoria and at Ottawa were shown and the interpretation of the various waves given. In a series of slides and epidiagrams, showing earthquakes at several different distances from the observer, the types of waves, especially those which were reflected from the earth's crust or its core, were clearly shown. Dr. Pearce concluded the talk with a brief discussion of the structure of the earth and the theory of the "liquid core".

After a number of questions which showed the interest of the audience Mr. O. M. Prentice moved a vote of thanks to the speaker for his clear exposition of a difficult subject and the meeting then adjourned.

February 14, 1940.—The second meeting for 1940 of the Victoria Centre of the R.A.S.C. was held in the Y.W.C.A. Parlours on Wednesday, February 14, with the president, Mr. Robert Peters, in the chair. Following the reading of the minutes, silent tribute was paid to the memory of Lord Tweedsmuir.

Miss Hailstone briefly reviewed Spencer Jones' book, "Worlds Without End" and then commented on current phenomena. After emphasizing the unusual grouping of the planets during February, she asked everyone to count the number of stars of first magnitude or brighter, visible at 9 p.m. on a clear night. The president then called on Dr. Beals to introduce the speaker of the evening, Dr. A. M. Crooker, Professor of Physics at the University of British Columbia.

In introducing his subject, "Sources of Solar and Stellar Energy," Dr. Crooker suggested a sub-title, "Why Do The Stars Shine?". The methods of studying starlight by means of the spectrograph and powerful telescopes were first discussed and it was shown that the sun is an average star according to the mass-luminosity law; hence any theory which explains stellar energy must apply to the sun. As an apt example of the tremendous energy released by the sun, the lecturer said that if the sunlight falling on the decks of the battship *Hood* could be turned into energy, fifteen tons of fuel an hour would be obtained.

In studying the theory of stellar energy, the speaker emphasized that the sun could not be considered as "burning" in spite of the tremendous heat it gives off. Kelvin's contraction theory would allow a life of only 10^7 years, which is too short for an average star, and if radioactivity were the source of the energy, it would mean that the more massive stars would contain more radioactive elements—which seems unlikely.

A more promising field of investigation was opened up by the modern theory of the equivalence of mass and energy. This led up to the transmutation of elements, the dream of the alchemists. Dr. H. A. Bethe of Cornell had studied these reactions exhaustively and came to the conclusion that one series could be used to explain stellar energy:

(1) $C^{12}+H \rightarrow N^{13}$; (2) $N^{13} \rightarrow C^{13}+\epsilon$; (3) $C^{13}+H \rightarrow N^{14}$;
(4) $N^{14}+H \rightarrow O^{15}$; (5) $O^{15} \rightarrow N^{15}+\epsilon$; (6) $N^{15}+H \rightarrow He^4$.

Beginning with the available supply of carbon and hydrogen, a series of reactions were studied in which nitrogen and oxygen were formed, but the final reaction between nitrogen and hydrogen formed carbon and helium. Thus the carbon remained unchanged and the hydrogen was transformed into helium plus a great deal of energy. As most of these reactions had been verified by laboratory experiments, and as the energy thus released agreed with that necessary for main-sequence stars, this theory at present was looked upon with favour by leading physicists and astronomers.

Following the lecture, Dr. Crooker was asked to give further details concerning this modern theory and explained difficult points to the satisfaction of everyone. After a most interesting period of questions, a hearty vote of thanks to the speaker was moved by Mr. K. O. Wright and the audience enthusiastically concurred. The meeting then adjourned at 9.50 p.m.

KENNETH O. WRIGHT, *Recorder*.

March 6, 1940.—The meeting, held as usual at the Y.W.C.A., was called to order by the president, Mr. Robert Peters, very shortly after 8 p.m. After presenting data upon the number of stars of the first magnitude or brighter visible in the evening sky at present, Mr. Peters called upon Dr. J. A. Pearce to answer a question regarding the cause and nature of the zodiacal light. Dr. Pearce told of the zodiacal light being visible after sunset as a faint cone of light extending from the west along the ecliptic and went on to explain how astronomers believe it due to reflection of the light of the sun from a swarm of small meteoric particles. The librarian of Victoria Centre described briefly the book "Astronomy for the Millions" by Van den Bergh and recommended that members read it.

The President then called upon Professor R. T. Wallace of Victoria College to present the main address of the evening upon the subject "The Laws of Probability and their Applications". Professor Wallace commenced by indicating the connections between science and the laws of chance or probability, mentioning their application to the fields of modern theoretical physics, biological laws, and to statistics. The historical development of the laws of probability by Pascal, Fermat and others from the first half of the 17th century was traced by the speaker who told how this branch of mathematics began through persons interested in gambling games posing problems to mathematicians. How the so-called "Pascal Triangle", closely related to the later discovered Binomial Theorem, was used to solve such problems in combinatory analysis was indicated and the fundamental foundations of the subject laid in the 18th and 19th centuries by Laplace and by Gauss were sketched.

Professor Wallace next gave numerous interesting examples of Probability using, for purposes of illustration, bridge hands and throws of dice, and he stressed the fundamental difference in viewpoint of, say, a sweepstake from the points of view of promoter and participant. Continuing to the more serious applications of the laws of probability, the lecturer closed by outlining the uses of probability in connection with polls of public opinion, the Mendelian laws of heredity, the setting of life insurance rates and, finally, the development of modern theoretical physics and chemistry.

Numerous questions asked the speaker by members of the audience testified to the general interest aroused by the excellent lecture. After a vote of thanks to Professor Wallace proposed by Miss Humeston on behalf of the centre was heartily endorsed by everyone present, the meeting adjourned.

ANDREW MCKELLAR, for *Recorder*.

March 27, 1940.—After a word of greeting to those present by the President, Mr. Peters, who was in the chair, Miss Hailstone, the librarian, very briefly reviewed and recommended to the centre the book by W. M. Smart entitled "The Sun, the Stars and the Universe". Mr. Peters remarked upon having observed a very large group of spots on the sun on Sunday, March 24, and then

called upon Dr. R. M. Petrie to outline briefly some of the terrestrial effects of solar disturbances. This Dr. Petrie did, explaining how strong bursts of ultra violet radiation and clouds of electrified particles shot out from areas of solar disturbance, upon reaching the upper layers of the earth's atmosphere, affect it, hence causing the aurora as well as interference in telegraphic and short wave radio communication. Mr. Peters mentioned briefly the forthcoming annular solar eclipse to be seen as partial in Victoria about noon on April 7.

The speaker of the evening, Dr. John S. Stevenson, associate mining engineer of the Provincial Department of Mines, was introduced by Dr. A. McKellar. Dr. Stevenson commenced his address on "The Mineralogy of Meteorites" by listing the definitions and terms necessary for his discussion. He classified the known meteorites into three main divisions, (1) iron meteorites or siderites, (2) stoney meteorites or aerolites, and (3) iron-stone meterites or sidereolites; each division could itself be classified into sub-groups. After giving brief histories of some of the largest and most interesting meteorites, Dr. Stevenson took up several questions, among them being the pitted nature of meteorites, their crusts and the various elements and compounds found in them. Some 39 of the 92 chemical elements have been detected in these bodies as well as many compounds, including some found in ultra-basic rocks in the earth. The siderites contain mostly iron-nickel compounds, and the aerolites mainly silicas such as olivine. Treating the origin of meteorites, the lecturer stated that many older ideas had been abandoned in favour of the one that they are parts of a shattered planetoid or planet that once had a spherical form and had cooled, as did the earth, gradually with varying degrees of speed. The address was concluded by projecting a number of pictures of meteorites on the screen to illustrate the points the lecture had brought forward, and by a plea to all present to keep a constant look-out for strange-appearing rocks which might be meteorites.

After numerous questions had been answered by Dr. Stevenson, and a hearty vote of thanks had been tendered him for his excellent address, the meeting adjourned at 9.55 p.m.

ANDREW MCKELLAR, for *Recorder*.

April 17, 1940.—The president, Mr. Robert Peters, opened the meeting at 8.15 p.m. and called for the minutes of the previous meeting. Miss Hailstone briefly reviewed and recommended the book, "A Twentieth Century Atlas of the Heavens" by Thomas Heath. "The Climate of the Yukon" was the topic of a short address by Mr. A. G. Berton, who had recently returned from Dawson. He discussed the temperatures, which range from 93° to -72° F., the midnight sun, sun-dogs, and showed pictures of typical Yukon scenes.

As the feature of the evening, Mr. Leonard Hopkins gave a lecture on "How to Make a Telescope" in which he gave explicit instructions for all operations and demonstrated the necessary tools. After briefly reviewing the types of telescope, the speaker suggested that an amateur could easily make a

6¼"-reflector of 50" focal length. The materials necessary, the methods of preparing the tools and the technique of grinding were explained and then the three methods of determining the concavity were shown: (1) by means of a template; (2) with a wire of thickness equal to the depth of glass to be removed and a straight-dge; and (3) by means of a lamp and the image obtained at the centre of curvature. Both rough and fine grinding were discussed and then the speaker showed how to make a pitch "lap" which is necessary for the polishing and parabolizing operations. The talk was brought to a close with a thorough discussion of the Foucault knife-edge test and the interpretation of the various forms taken by different surfaces.

After the lecture a number of questions were asked the speaker and, following a hearty vote of thanks, the meeting adjourned at 10.15 p.m.

KENNETH O. WRIGHT, *Recorder.*

AT VANCOUVER

January 9, 1940.—The sixty-eighth meeting of the Vancouver Centre of the Royal Astronomical Society of Canada was held in Room 200 of the Science Building of the University of British Columbia. The president, Mr. C. A. McDonald, was in the chair. The speaker of the evening was Dr. K. C. Mann, of the staff of the Physics Department of the University of British Columbia, who had chosen for his topic "Sources of Stellar Energy." Dr. Mann first presented several empirical laws giving relationships between the internal temperatures of stars and their mean molecular weights. Our sun, which generates 5 x 10^{23} horse power, and which consists of approximately 35 per cent hydrogen, has a temperature at its centre of approximately 19,000,000° C. He pointed out that the coolest stars are those containing a large amount of hydrogen. The lecture then dealt with various possible sources of stellar energy, namely (a) chemical action, (b) contraction of the surface as given in the Helmholtz contraction theory, and (c) radioactivity, and showed how these would provide energy for only a relatively short period. He then considered the recent work of H. A. Bethe, of Cornell University, in which the liberation of energy in the sun is accounted for in terms of artificial nuclear disintegrations. This worker has succeeded in choosing a series of possible nuclear reactions that gives a reasonable value for the energy output per second of the sun. Carbon, nitrogen, and hydrogen nuclei are involved in the cyclical change of nuclear transformations. Carbon and hydrogen are the two elements entering into the primary reaction, but the net result of the cycle is that the amount of carbon remains constant, while the hydrogen is transformed gradually over into helium, with a loss of mass, which is dissipated in the form of radiant energy. Although this loss of mass is at the rate of 4.2 millions of tons per second, the sun can last at least 10 billions of years, and is now in the first part of its life.

A lively discussion, in which many of the members participated, followed

this interesting and inspiring address. The thanks of the Society were tendered to Dr. Mann by the president.

February 13, 1940.—The sixty-ninth meeting of the Vancouver Centre of the Royal Astronomical Society of Canada was held in Room 200 of the Science Building of the University of British Columbia. The president, Mr. C. A. McDonald, was in the chair, and introduced the speaker of the evening, Mr. Leonard Chatwin, of the Department of University Extension of the University of British Columbia, who delivered a very interesting and beautifully illustrated lecture on "Colour Photography."

The majority of the forty distinct processes of colour photography that have been developed since 1890 fall into the class of additive processes, and rest on the theory that the three primary colours, blue, green, and red, may be added to give white light. The more important commercial examples of this group are the Paget, the Lumière Autochrome, the new Lumière Filmcolor, the Agfacolor, the Dufaycolor and Finlay processes. The value of a given process depends on its success in furnishing a large number of small blue, green, and red filters on the plate. In one process, dyed grains of starch are used; in another, dyed grains of resin; in a third, the colour filter screen is ruled on the plate. However, the additive processes have two major disadvantages, a low transmission power of about 10 per cent, and a lack of definition due to the individual filter grains being visible in the image.

In recent years the trend has been to the subtractive processes. Here we have yellow, magenta and blue-green referred to as the subtractive primaries because they are obtained by subtracting the primary colours—blue, green, and red—from white light. Instead of three black and white images as in the additive process, here we have three coloured images—yellow, magenta, and blue-green—superimposed. As the white light passes through these, some colour will be absorbed or subtracted at each layer where they happen to overlap, hence the name "Subtractive" Process."

The most important subtractive processes in use today are the Technicolor, Kodachrome, and the Agfa-Neuchrome processes. The first two types employ identical processes. With Technicolor, however, three separate films are used, while in the case of Kodachrome we have only one film five-thousandths of an inch in thickness consisting of five layers made up of three emulsions and two dyed gelatin filters. The speaker gave a lucid description of the thirteen involved operations in the processing of Kodachrome film. The Agfa-Neuchrome process is thought by many to give results superior to the Kodachrome process at lower cost. It is not yet available on this continent, although in general use in Europe for the past four years.

The speaker then projected on the screen examples of work he had done with the various processes, climaxing a very enjoyable evening with the showing of a beautiful coloured moving picture of the campus and surrounding mountain scenery.

H. D. Smith, *Secretary.*

AT EDMONTON

December 14.—The annual banquet was held in the Corona Hotel. After the business of the meeting had been transacted, the guest speaker, Dr. S. W. Dyde, gave an interesting and scholarly paper on "Shakespeare and the Stars", illustrated by numerous quotations from the poet rendered in his own eloquent and inimitable style.

Although Shakespeare was born in the same year as Galileo, and was a contemporary of Kepler, the Copernican theory was not yet common knowledge in Shakespeare's day, and he accepted the current Ptolemaic views. Such knowledge of the stars as he had was probably picked up mainly in conversations with friends and acquaintances, but he certainly recognized the wonder and glory of the heavens and was familiar with much of its mythology. References to the "centric earth", the "axle-tree" of the Universe, and the music of the spheres were borrowed from Marlowe and Montaigne. Comets and eclipses were commonly supposed in Shakespeare's time to portend events on earth, and most people believed in astrology, but there is evidence that Shakespeare preferred to say with Cassius that "the fault, dear Brutus, is not in our stars, but in ourselves." (See this JOURNAL, pp. 49-58, 1940.)

AT WINNIPEG

April 10, 1940.—The regular monthly meeting of the Royal Astronomical Society of Canada, Winnipeg Centre, was held in Theatre F, University Building, at 8.15 p.m. The president, Mr. L. J. Crocker, was in the chair.

Mr. R. D. Colquette, as usual, spoke for five minutes about "Astronomy and the News." He said that recently those peculiar formations, previously believed to be meteorite craters in South Caroline, have been determined to be basins of old ponds caused by springs.

Mr. R. S. Evans followed with a short talk explaining some excellent photographs which he had taken during a period of ten days. He had prepared to take these pictures before he knew of the presence of sun spots but expected to find some because of the intense auroral display. The first picture was taken on Monday, March 25, with a three-inch refractor and a red filter and clearly showed a tremendous cluster of spots in the north central region of the sun besides several other separate spots. Photographs on succeeding days showed the same spots moved by the rotation of the sun. On April 7 Mr. Evans took some excellent pictures of the partial eclipse of the sun. A large sun-spot almost touched the dark limb of the moon.

As it was members' night there were two addresses. Mr. W. P. Johnson was the first speaker. His topic was "Colour."

He commenced by stressing the importance of vision in receiving impressions. He next described briefly the Hertzian, light and heat, ultra-violet, X, Gamma and Cosmic rays.

A demonstration of a little more than one per cent of these rays followed. Refraction and absorption of white light with prisms, etc., followed. Ultra-violet rays were made to show fluorescence with minerals, salts and oils. The effects of X-rays produced by cathode rays were made to show magnetic deflections, cast shadows, heat by percussion, do mechanical work and show fluorescence. The elaborate apparatus and presentation was most interesting to everyone.

The second speaker was Mr. V. C. Jones, whose topic was "A Planetarium." This apparatus is the result of almost two years' labour. As it is of considerable scientific value a full account will likely be given in the JOURNAL. One interesting result of this work was that the planetarium could be used to answer the challenge of a speaker (Mr. C. H. Dickins) regarding the times of sunrise and sunset for latitudes north of 60°.

May 8, 1940.—The last regular meeting for this season was held in theatre F of the University of Manitoba at 8.15 p.m., with the president, Mr. L. J. Crocker, in the chair.

The speaker of the evening was the beloved honorary president of the Winnipeg Centre, Monsignor T. W. Morton, who chose as his subject, "The Mythology of the Stars."

He began by saying that mythology started as fables with purposes, so that their truths might be remembered. Metaphors, similes and allegory were used and so well were the tales told that history, philosophy, religion and human conduct have been influenced up till to-day.

The mythology of the planets and many stars was then told in such an interesting and arresting manner that each person in the audience hoped that this wonderful scholar and teacher, whose age is seventy-eight years, would be spared many more seasons to entertain and instruct.

OLIVE A. ARMSTRONG, *Recorder.*

AT TORONTO

December 12, 1939.—The regular meeting of the Royal Astronomical Society of Canada, Toronto Centre, was held in the McLennan Laboratory, University of Toronto, on December 12. The chairman, Mr. S. C. Brown presided.

Mr. Brown announced that the next meeting would be sometime in January, the date to be announced later. He also reminded the members of the Jubilee of the Society to be celebrated this year. The members of the A.A.V.S.O. are planning to hold their spring meeting here. Mr. Brown asked the members to remain for the annual election at the close of the present meeting.

The main part of the meeting was given over to an Astronomical Information Please with Dr. F. S. Hogg in charge. Team A consisted of: Mr. Collins, Mr. Waring, Mr. Best, Mr. Sherrick, Mr. Patterson, and Mr. Mason. Team B:

Mr. Brown, Mr. Hassard, Mr. Horning, Mr. Plummer, Mr. McNabb, and Mr. Duncan.

The teams were asked questions alternately. A point was scored for a correct answer. If a team failed to answer in the allotted time the other team was given the opportunity of answering and of getting an extra point. There was close rivalry between the teams. Finally team B won by a scant margin. The programme was very successful.

Dr. Hogg discussed the procession of the equinoxes, which was known in early times. The pole does not stay fixed, but moves around in a circle of diameter 47° in 26000 years. Though this motion is very slow, it can be detected in 10 years by photography.

The axis of the earth is not at right angles to the plane of its orbit. The force exerted by the sun and moon on the equatorial bulge in trying to bring the equator down to the ecliptic is resisted by the rotating earth by a conical motion of the axis. The line of intersection of the equator and ecliptic moves around with the earth in this period of 26000 years.

The evidences of this motion are the following:

1. Conical motion of the pole.
2. Westward motion of the equinoxes, amounting to about 50″ per year.
3. Changing right ascension and declination.
4. Kinds of year. We use the tropical year rather than the sidereal year to keep the seasons stationary. The difference between the years is the amount the first point of Aries moves in one year.
5. Length of day. The day we use is similarly corrected for the amount the first point of Aries moves in one day.

Dr. Hogg discussed also the effect of this motion on the climatic conditions on the earth. At present the pole of the earth is away from the sun when the earth is closest to the sun in its orbit. 13000 years from now the northern hemisphere will have winter when farthest from the sun.

RUTH J. NORTHCOTT, *Recorder.*

The Royal Astronomical Society of Canada

OFFICERS FOR 1940

Honorary President—The Hon. Leonard J. Simpson, M.D., Minister of Education for the Province of Ontario.
President—J. A. Pearce, Ph.D., Victoria, B.C.
First Vice-President—F. S. Hogg, Ph.D., Toronto.
Second Vice-President—Miss A. V. Douglas, Ph.D., Kingston.
General Secretary—E. J. A. Kennedy, Toronto.
General Treasurer—J. H. Horning, M.A., Toronto.
Recorder—R. H. Combs, Toronto.
Librarian—P. M. Millman, Ph.D., Toronto.
Curator—R. S. Duncan, Toronto.
Council—D. S. Ainslie, M.A., Ph.D., Toronto; Major E. H. Anundson, London, Ont.; D. W. Best, D.D., Toronto; H. Boyd Brydon, Victoria; J. W. Campbell, M.A., Ph.D., Edmonton; Dean Henry F. Hall, Montreal; E. A. Hodgson, M.A., Ph.D., Ottawa; J. A. Marsh, M.P., Hamilton, Ont.; A. Thomson, M.A., Toronto; L. A. H. Warren, M.A., Ph.D., Winnipeg; and Past Presidents—Sir Frederick Stupart; C. A. Chant, M.A., Ph.D., LL.D.; A. T. DeLury, M.A.; J. S. Plaskett, D.Sc., F.R.S.; A. F. Miller; J. R. Collins; W. E. W. Jackson, M.A.; R. M. Stewart, M.A.; A. F. Hunter, M.A.; W. E. Harper, M.A., D.Sc.; H. R. Kingston, M.A., Ph.D.; R. K. Young, Ph.D.; L. Gilchrist, M.A., Ph.D.; R. E. DeLury, M.A., Ph.D., and the presiding officer of each Centre.

TORONTO CENTRE

Honorary Chairman—Dr. C. A. Chant
Chairman—S. C. Brown
Vice-Chairman—Dr. D. W. Best
Secretary—F. L. Harvey, 3019 Queen St. E.
Recorder—Miss Ruth J. Northcott, M.A.
Treasurer—T. H. Mason
Curator—R. S. Duncan
Council—Dr. D. S. Ainslie; Dr. L. Gilchrist; Dr. J. F. Heard; Dr. F. S. Hogg; J. H. Horning; Dr. P. M. Millman; Rev. C. H. Shortt; Tracy D. Waring; Dr. R. K. Young; and Past Chairmen J. R. Collins; A. R. Hassard; and E. J. A. Kennedy.

WINNIPEG CENTRE

Honorary President—T. W. Morton
President—L. J. Crocker
First Vice-President—C. A. E. Hemsley
Second Vice-President—Miss O. A. Armstrong
Treasurer—R. S. Evans, 10 Ruskin Row
Secretary—Miss Margaret E. Watterson, 612 Toronto General Trusts Building
Press Secretary—Miss O. A. Armstrong, 520 Maryland Street
Council—Mrs. J. Norris; Dr. L. A. H. Warren; Rev. Father Burke-Gaffney; V. C. Jones; W. R. Junkin; L. W. Koser; H. E. Riter; A. W. Smith; and R. D. Colquette (past president).

OTTAWA CENTRE

Honorary President—John McLeish, B.A.
President—Miriam S. Burland, B.A.
First Vice-President—F. W. Matley, Esq.
Second Vice-President—T. L. Tanton, Ph.D.
Secretary—Malcolm M. Thomson, B.A., Dominion Observatory
Treasurer—Andrew C. Steedman, B.A.
Council—Hoyes Lloyd, M.A.; C. B. Reilly, K.C.; W. W. Nichol, B.A.; R. G. Madill, B.A.; and A. H. Miller, M.A. (Oxon).

MONTREAL CENTRE

Honorary President—Mgr. C. P. Choquette
President—Frank J. de Kinder
Vice-President—Prof. A. H. S. Gillson
Secretary-Treasurer—Henry F. Hall, Sir George Williams College, 1441 Drummond St., Montreal
Council—Dr. C. C. Birchard; O. A. Ferrier; G. Harper Hall; G. R. Lighthall; W. E. Lyman; E. R. Paterson; J. Addison Reid; Dr. A. Norman Shaw; A. M. Donnelly; F. P. Morgan.

LONDON CENTRE

Honorary President—Dr. H. R. Kingston
President—Rev. W. G. Colgrove
Vice-President—T. C. Benson
Secretary-Treasurer—Dr. G. R. Magee, 427 William St.
Council—Miss S. Livingstone; D. M. Hennigar; O. Kilburn; E. E. O'Connor; M. O. Culbert; and Past President J. Higgens.

VICTORIA CENTRE

Honorary President—Lt.-Com'dr H. R. Tingley
President—Robert Peters
First Vice-President—R. M. Petrie, M.A., Ph.D.
Second Vice-President—Capt. Wm. Everall
Secretary-Treasurer—Miss Phoebe Riddle, 804 Seymour Ave.
Recorder—K. O. Wright, M.A.
Librarian—Miss C. Hailstone
Council—L. Hopkins; Miss K. Langworthy; A. McKellar, Ph.D.; O. M. Prentice; James Smith; W. A. Thorn; A. H. Young; and Past Presidents G. Shaw and H. Boyd Brydon.

HAMILTON CENTRE

Honorary President—W. T. Goddard
President—N. H. Broadhead
Vice-President—Rev. E. F. Maunsell
Curator—T. H. Wingham
Secretary-Treasurer—H. B. Fox, 257 Balmoral Avenue N.
Council—Dr. Wm. Findlay; Dr. A. E. Johns; J. A. Marsh, M.P.; Geo. E. Campbell, M.A.; E. E. Bossence; F. H. Butcher, B.A.; Wm. D. Stewart.

VANCOUVER CENTRE

Honorary President—Dr. J. A. Pearce
President—C. A. McDonald
Vice-President—Dr. A. M. Crooker
Corresponding Secretary—Dr. K. C. Mann, University of British Columbia
Recording Secretary—Dr. H. D. Smith
Treasurer—Mrs. Laura Anderson
Council—C. Jorgensen; Mrs. C. A. Rogers; E. C. Thrupp; F. R. Stewart; A. Outram; Dr. R. Hull; C. E. Bastin; N. D. B. Phillips

EDMONTON CENTRE

Honorary President—Dr. J. W. Campbell
President—John Blue
Vice-President—H. B. Doughty
Secretary—Dr. E. H. Gowan
Treasurer—E. N. Higinbotham
Librarian—Dr. E. S. Keeping
Council—W. O. Coulman; Mrs. J. A. Clarke; C. G. Wates; W. A. McAulay; C. P. Willoughby

THE ROYAL ASTRONOMICAL SOCIETY OF CANADA
1890-1940

This year marks the completion of the first fifty years of the corporate existence of our Society. The Society was incorporated in 1890 under the name of The Astronomical and Physical Society of Toronto, and assumed its present name in 1903.

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal, P.Q.; Ottawa, Toronto, Hamilton and London, Ont.; Winnipeg, Man.; Edmonton, Alta.; Vancouver and Victoria, B.C. As well as about 700 members of these Canadian Centres, there are over 200 members not attached to any Centre, mostly resident in other nations, while some 300 additional institutions or persons are on the regular mailing list for our publications.

The Society publishes a monthly JOURNAL containing about 500 pages and a yearly OBSERVER'S HANDBOOK of 80 pages. Single copies of the JOURNAL or HANDBOOK are 25 cents, postpaid. In quantities of 10 or more copies, the price is 20 cents a copy.

Membership is open to anyone interested in astronomy. Annual dues, $2.00; life membership, $25.00. Publications are sent free to all members or may be subscribed for separately. Applications for membership or publications may be made to the General Secretary, 198 College St., Toronto.

The year 1940 also marks the hundredth anniversary of the founding in Toronto of the first Observatory (magnetic) in Canada. This was one of the first magnetic observatories in the world and became the nucleus of observatory development in Canada.

The Society has for Sale:

Reprinted from the JOURNAL of the Royal Astronomical Society, 1936-1939.

The Physical State of the Upper Atmosphere, by B. Haurwitz, 96 pages; Price 50 cents postpaid.

The Small Observatory and its Design, by H. Boyd Brydon, 48 pages; Price 25 cents postpaid.

General Instructions for Meteor Observing, (revised 1940) by Peter M. Millman, 24 pages; Price 15 cents postpaid.

Two Inexpensive Drives for Small Telescopes, by H. Boyd Brydon, 12 pages; Price 10 cents postpaid.

A. H. Young's Simple Mounting for the 6-inch Reflector, by H. Boyd Brydon, 16 pages; Price 10 cents postpaid.

Send Money Order to 198 College St., Toronto.